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EVALUATION OF THE FLUIDIZED-BED COMBUSTION PROCESS
VOLUME III. PRESSURIZED FLUIDIZED-BED BOILER DEVELOPMENT PLANT DESIGN

WESTINGHOUSE RESEARCH LABORATORIES

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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VOLUME III -

PRESSURIZED FLUIDIZED-BED BOILER DEVELOPMENT PLANT DESIGN

by

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The results, conclusions, and recommendations presented in this volume represent the combined work and thought of many persons at Westinghouse and the Office of Research and Development (ORD). Westinghouse subcontracted Foster Wheeler Corporation to prepare the preliminary design package.

In particular, we want here to express our high regard for and acknowledge the contribution of Westinghouse personnel and the personnel at ORD who conceived the overall fluidized bed combustion boiler effort and who have defined, monitored, and supported the efforts of Westinghouse and others on the program. Mr. P. P. Turner, Chief of the Advanced Process Section, has served as EPA project officer on our work. Numerous enlightening and helpful discussions have been held with Mr. Turner; with section members D. Bruce Henschel and Sam Rakes; and with R. P. Hangebrauck, Chief of the Demonstration Projects Branch. Personnel from the Westinghouse Research Laboratories have made significant contributions. Dr. W. C. Yang, Mr. J. R. Hamm and Dr. R. W. Hornbeck participated in the development plant design and evaluation. Mr. P. J. Hopkins, Turbine and Generator Division, Westinghouse Canada Limited, performed an investigation into turbine suitability for the development plant. Mr. G. S. Howard and Mr. W. F. Stahl of the Westinghouse Gas Turbine Systems Divisions participated in the evaluation of the gas-turbine test facility. Mr. L. W. Zahnstecher, Foster Wheeler Corporation, served as project manager for preparation of the preliminary design. Foster Wheeler personnel made significant contributions through their expertise in boiler design.

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PREFACE

The Office of Research and Development (ORD) of the United States Environmental Protection Agency (EPA) has organized and is sponsoring a fluidized bed fuel processing program. Its purpose is to develop and demonstrate new methods for utilizing fossil fuels -- particularly coal and oil -- in utility power plants. These methods should:

- Meet environmental goals for SO_2, NO_x, ash, smoke emissions, and wastes
- Compete economically with alternative means for meeting these abatement goals.

Westinghouse Research, under contract to the Office of Research and Development (ORD) of the Environmental Protection Agency (EPA), is carrying out a study to evaluate and develop fluidized bed combustion and oil gasification in air pollution abatement. The goals of this work are:

- To identify which fluidized processes might be economically employed in utility power plants or industrial boilers to reduce SO_2, particulate, and NO_x emissions
- To assist in planning and implementing a program to develop the fluidized bed systems deemed effective in air pollution control and economical in steam/power production.

Tasks in the evaluation of fluidized bed combustion set forth by EPA which have been completed at Westinghouse under a previous contract are:

- To search the technical and patent literature in fluidized bed combustion, to canvass commercial organizations with expertise pertaining to this field, and to survey the market for industrial boilers and utility power systems

- To design a fluidized bed industrial boiler and two fluidized bed utility power systems -- one 300 MW capacity, the other 600 MW; and to provide performance and cost projections for the equipment designed
- To provide technical consultation and assistance on the ORD fluidized bed fuel processing program, including both combustion and gasification
- To conceptualize a development plant which will prove the configurational or operating features of the fluidized bed boiler designs not confirmed by prior art or experience
- To assess the effectiveness and economics of an atmospheric-pressure, fluidized bed oil gasification-combustion system and to aid in planning for a demonstration installation of such a system.

The results of these surveys, designs, evaluations, and comparisons were published in a three-volume report, "Evaluation of the Fluidized Bed Combustion Process," in November 1971 under contract No. CPA 70-9.

These results provided the basis for the work performed from July 1971 to May 1973 which is described in this four-volume report. Tasks in the evaluation of the fluidized bed combustion process set forth by EPA under contract 68-02-0217 have focused on the development of pressurized fluidized bed combustion for power generation and fluidized bed oil gasification for power generation. These tasks have included:

- Extensive process evaluation studies of the pressurized fluidized bed combustion system for power generation. These investigations predict the sensitivity of operating and design parameters selected for the base power plant design on plant economics; provide additional experimental data on sulfur removal and sorbent regeneration using limestones and dolomites; project economics and performance for various sulfur removal systems, both regenerative/sulfur recovery and once-through sorbent; establish a plant operation and control philosophy and evaluate alternative pressurized fluid bed combustion concepts, both economic and performance.

- Preparation of preliminary plans and a cost estimate for a 30 MW (equivalent) pressurized fluidized bed combustion boiler development plant. The design provides sufficient detail to locate a suitable plant site and to obtain a fixed cost bid for the preparation of detailed plans. The plant will provide the capability to study effectively the remaining technical problems to achieve the greatest potential for reducing emissions and to achieve economical power generation.

- Identification of a project team to demonstrate fluidized bed oil gasification/desulfurization for power generation. A cooperating utility -- New England Electric System (NEES) -- has been identified to carry out a 50 MW demonstration plant program. Further process evaluation has been carried out and experimental data obtained on sulfur removal and spent stone disposal.

- Evaluation of pressurized oil gasification for combined cycle power generation. Oil gasification process concepts and options have been reviewed, material and energy balances projected, performance projected, and capital and energy costs estimated.

- Provision of technical consultation and assistance on the ORD fluidized bed fuel processing program, including both combustion and gasification processes. Technical and economic comparisons have been carried out on various fluidized bed fuel processing systems and various conventional means of steam/power generation.

This volume (Volume III) contains the preliminary design of a 30 MW (equivalent) pressurized fluid bed boiler development plant. The design basis, design details, cost estimate, experimental program, and recommendations and alternatives for commercializing the process are presented. Volumes I and II contain the pressurized fluid bed combustion process evaluation studies. Volume IV presents the work on fluidized bed oil gasification/desulfurization.

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CONVERSION FACTORS -- ENGLISH TO METRIC UNITS

	English System	Metric Equivalent
Length	in	2.54 cm
	ft	0.305 m
Area	in^2	6.45 cm^2
	ft^2	0.0930 m^2
Volume	in^3	16.39 cm^3
	ft^3	28.32 l
	gal	3.785 l
Mass	oz	28.35 gm
	lb	453.6 gm
	ton	907.2 kg
Pressure	lb/in^2	51.70 mm Hg
	in H_2O	1.865 mm Hg
Temperature	°F	1.8 (°C) + 32
	°R	1.8 °K
Energy	Btu	252 cal
Power	Btu/min	252 cal/min

1. SUMMARY

A 30 MW (equivalent) pressurized fluid bed boiler development plant has been conceived to demonstrate pressurized fluid bed boiler operation. Such a plant is needed for further development of pressurized fluid bed combustion combined cycle power plants which offer an opportunity for minimizing sulfur dioxide, nitrogen oxide, and particulate emissions; reducing thermal emissions; increasing overall power plant efficiency; and producing electrical energy from fossil fuels with reduced capital and energy costs. The plant will provide the capability of studying fluid bed combustion and heat transfer, steam generation, solids feed and handling, particulate removal, gas-turbine performance, boiler control, and sulfur dioxide and nitrogen oxide emission control.

Preliminary designs, cost estimates, experimental program, schedule, and program alternatives are presented. This document and the support material will be used to locate a plant site, to obtain fixed cost bids for the preparation of detailed plans, and to form a team to implement the development plant program. Information received from continuing laboratory and pilot plant programs will be used to improve the development plant design and program.

Detailed design, construction, and operation of this plant is recommended for the three-year period 1974-1976 in order that a demonstration pressurized fluid bed combustion boiler power plant can be built and operated before the end of the decade. The capital cost for the nominal plant adjacent to a power plant is estimated to be approximately $10 million. Operating costs are estimated to be between $2.4 and 3 million per year, depending on the plant site.

2. INTRODUCTION

A recent technical and economic analysis for the Office of Research and Development, EPA,[1] has shown that power plants using pressurized fluidized bed boilers can be built which are:

- Economical in capital requirements. Estimated costs for such plants are 20 to 30% less than are those for conventional steam power plants.
- Efficient in operation. Pressurized fluidized bed boiler plants using conventional steam technology are equal in overall efficiency to the best of conventional plants -- about 38%; the use of increased steam temperatures and pressures and of increased combustion gas temperatures will increase overall plant efficiency to 46% or more.
- Effective in pollution abatement. Pressurized fluidized bed boiler power plants meet emission requirements established for SO_2, NO_x, and particulates.

Pressurized fluidized bed combustor test units have and are being operated to obtain data on sulfur removal; nitrogen oxide minimization; particulate emissions; boiler tube materials; gas-turbine component corrosion, erosion, and deposition and coal feeding. These units include bench-scale tests and pilot plant units of ∿ 1 MW equivalent capacity. A larger fluidized bed combustion boiler facility is now required to demonstrate:

- Operation of deep fluid beds with commercial heat transfer surface
- Operation of multiple beds
- Particulate removal system capability and reliability
- Gas-turbine reliability
- SO_2 and NO_x pilot plant emission results.

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Several concepts have been considered for a demonstration facility to extend the current program and commercialize the pressurized fluid bed boiler concept. The following alternatives illustrate the options available:

- Demonstrate the boiler concept with a single fluid bed unit (20 to 30 MW). The plant could stand alone as a development plant or might be integrated with an existing steam-turbine system and/or a process steam supply system.
- Demonstrate the plant concept with a multiple bed unit and gas turbine (75 to 150 MW). The plant could be a new integrated facility with steam-turbine power generation and/or process steam production, or it could be retrofitted on an existing steam-turbine plant.

The choice of a development/demonstration facility will depend on the available funds, the project team, and the location of a site. A preliminary design of one concept -- a single bed development plant -- has been prepared to provide a basic plant concept and cost data for assembling the project team.

A preliminary design has been prepared for a 30 MW pressurized fluidized bed boiler development plant. The design package was prepared by Foster Wheeler under contract to Westinghouse. The boiler comprises a single fluidized bed of 5 ft x 7 ft rectangular cross-section. Bed depths of 3 to 30 feet are possible to accommodate tubes for steam generation. The boiler represents a single bed in a module of a 300 MW power plant boiler. Alternative designs investigated include construction adjacent to a power plant and construction at an independent site; fluid bed combustor pressures of 170 psig and 320 psig; and coal feed rates from 22,000 lb/hr and 33,000 lb/hr.

Four approaches to sulfur removal were considered for the development plant:

- Once-through operation
- Integral boiler -- regeneration -- (sulfur recovery) system
- Two partially independent systems -- boiler and regenerator/(sulfur recovery)
- Regeneration system with flexibility to evaluate alternative regeneration/sulfur recovery processes.

The plant is designed to study the once-through limestone or dolomite sulfur removal system. This is recommended for the first generation plant based on the sulfur removal system study (Volume I) which weighed the energy requirements, economics, make-up stone requirements, and environmental parameters. Provisions are made for a regeneration system to be added at a later date.

This demonstration boiler plant would obtain data for the design, construction, and operation of a demonstration power plant based on pressurized fluidized bed combustion. The preliminary plans provide a basis for detailed designs and for overall planning through the preparation of site requirements, program schedules, and cost estimates specific for any proposed site. The plans will be useful also in gathering technical ideas for the development plant and in focusing attention on the technical problems which it must solve.

The Appendix presents the plans and estimates for the plant. The assembling of a United States government, industry, and utility team will be required to undertake the financing, construction, and operation of the plant.

3. BACKGROUND INFORMATION

A 635 MW pressurized fluidized bed combustion boiler power plant has been designed.[1] The power cycle schematic is shown in Figure 1. Operating at elevated pressure, a fluidized bed combustor requires a compressor to pressurize the air and to overcome the pressure loss over the fluidized bed combustor. At an operating pressure of 10 to 15 atmospheres, excess air of 10 to 15%, and fluidizing velocity of 6 to 12 ft/sec, a depth of 8 to 15 feet is required to accommodate the heat transfer surface in the bed; the pressure loss over the bed is thus four to eight times as large as that over an atmospheric-pressure bed. The pumping energy, however, is actually less because of the greater density of the gas at high pressure. Energy can be recovered from the high-temperature, high-pressure gases by passing them directly into a gas-turbine expander, reducing their pressure to atmospheric as shown in Figure 1. This expansion lowers the temperature of the gases by 600 to 800°F, thereby reducing the amount of surface required to recover heat from the combustion gases leaving the fluidized bed. The pressurized system can be operated at higher excess air rates. Such operation increases the fraction of gas-turbine power, reduces combustible losses from the boiler, and increases the waste heat recovery after the gas turbine. It also results in improved plant efficiencies.

Several boiler systems have been built, tested, or proposed which incorporate fluidized bed combustion. These systems, as well as alternative concepts, have been evaluated. The early concepts did not incorporate heat transfer surface or sulfur removal in the bed, and were generally designed to burn low-grade fuels. The heat released was extracted from the combustion gases during their passage through a conventional boiler. Recent concepts and studies incorporate heat transfer surface in the bed to achieve a more compact and efficient design and/or remove sulfur during the combustion process by using a limestone bed.

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Dwg. 6182A71

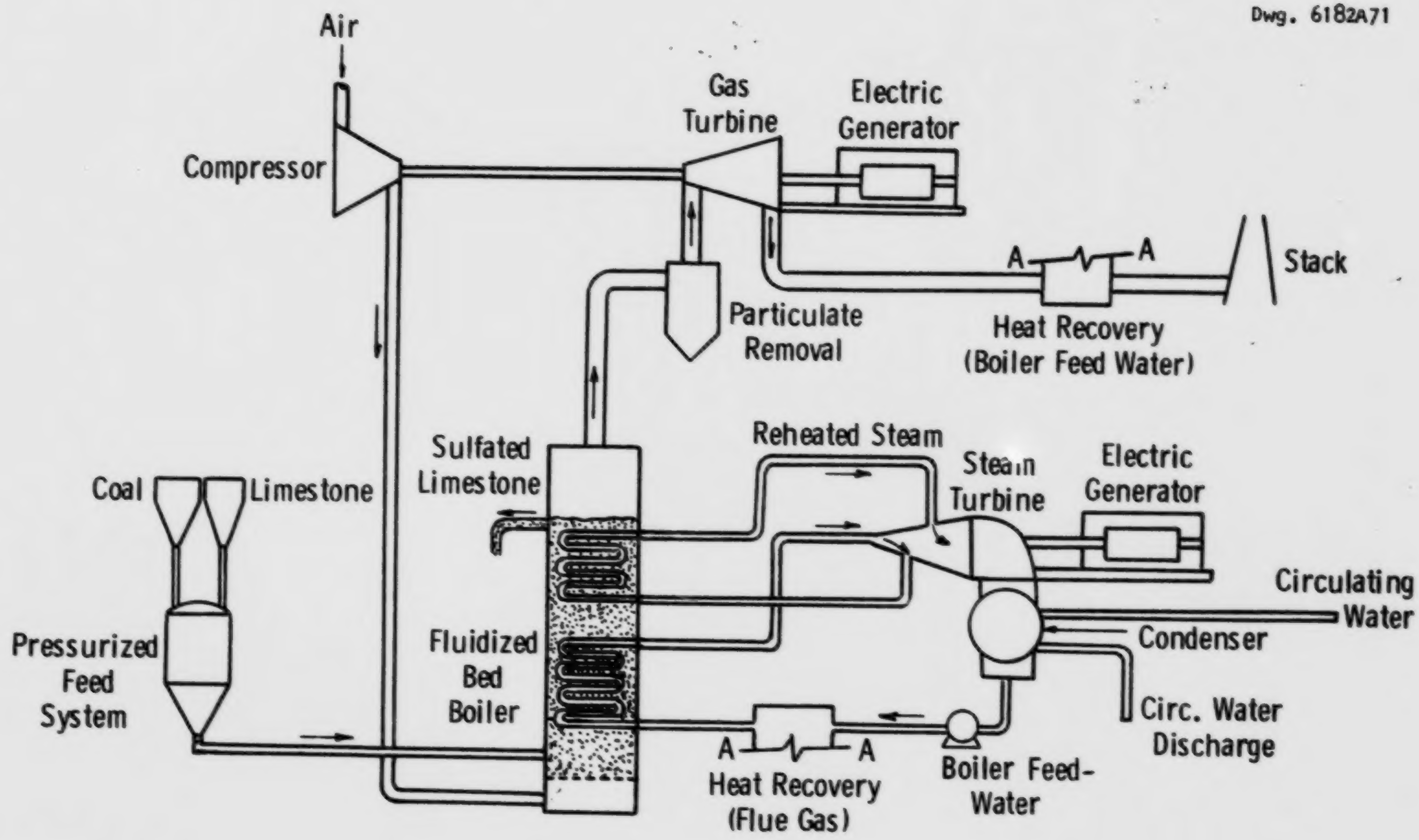

Figure 1–Pressurized Fluidized Bed Boiler Power Plant

The boiler design considered most promising consists of four modules. The modularized design provides for a maximum of shop fabrication and standardization, and assists in meeting the turndown requirements for the plant. Each module includes four primary fluidized bed combustors, each containing a separate boiler function -- one bed for the preevaporator, two beds for the superheater, and one bed for the reheater. Evaporation takes place in the water walls. All of the boiler heat transfer surface is immersed in the beds, except for the water walls. There is no convection heat transfer surface since the maximum allowable bed temperature is less than the state-of-the-art gas-turbine temperature. The fluidized bed combustors are stacked vertically because of the advantages in gas circuitry, steam circuitry, and pressure vessel design of deep beds. Each module contains a separate fluidized bed or carbon burn-up cell (CBC) to complete the combustion of any carbon elutriated from the primary beds. A separate bed may not be required since carbon losses may be low enough in the proposed pressurized boiler design with deep beds. A CBC is not envisaged if the system is operated with high excess air, which has the attraction of increasing plant performance by increasing the fraction of gas-turbine power. A simplified drawing of a module is shown in Figure 2. The 318 MW plant module can be shop-fabricated and shipped by rail. The 635 MW plant module is designed to be shipped in sections, each shop-fabricated. The primary beds for a 318 MW plant are approximately 5 ft x 7 ft. The bed depths are approximately 12 ft -- sufficient for the required heat transfer surface. The carbon burn-up cell (CBC) is approximately 2 ft x 7 ft. The CBC contains no submerged surface in the bed. The submerged tube bundles are formed by vertical tube platens or planes, each platen a continuous boiler tube in a serpentine arrangement. A platen is schematically represented in Figure 2. The heat transfer surface can be viewed as horizontal tubes. The preevaporator and reheater contain 1-1/2-inch diameter tubes; the evaporator water walls and reheater bed contain 2-inch diameter tubes. Details of the boiler design and the plant layout are presented elsewhere.[1]

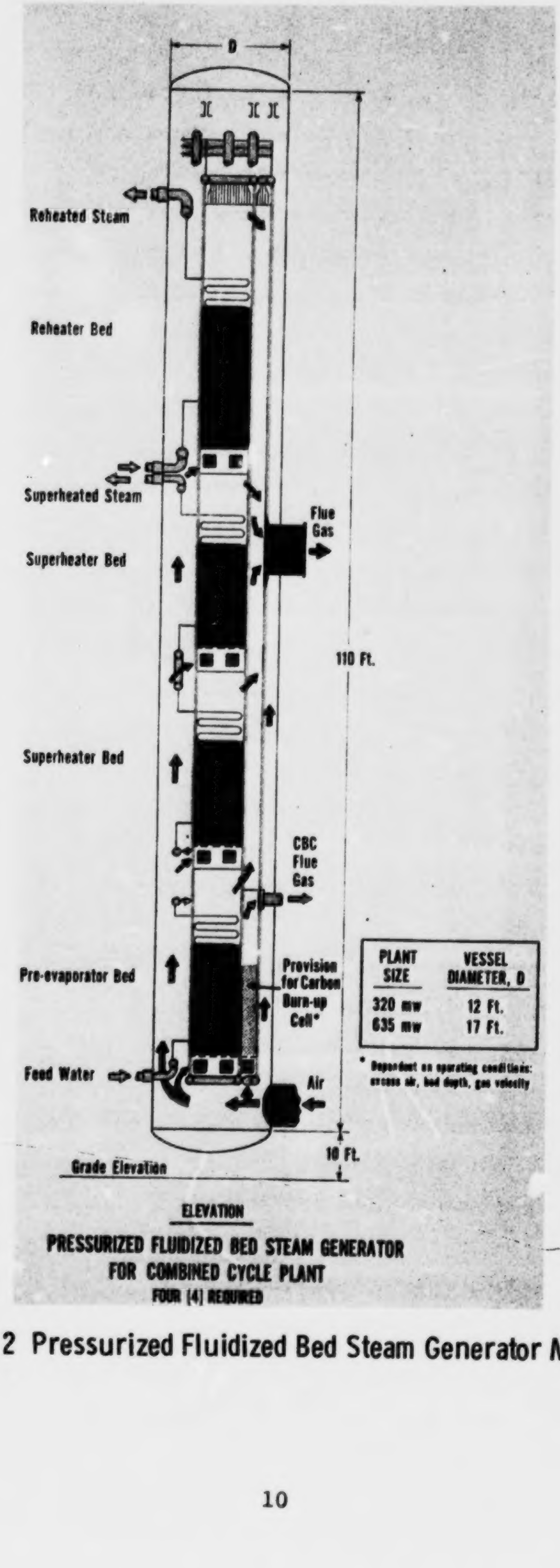

Figure 2 Pressurized Fluidized Bed Steam Generator Module

The effectiveness and economics of a pressurized fluidized bed boiler power plant have been evaluated.[1] Demonstrated SO_2 and NO_x reductions are adequate to meet emission standards. Energy costs are projected to be ∿ 10% less than conventional power plants using current power generation technology. There is thus a large economic margin for solving technological problems, and there is also the potential for increasing performance and reducing costs by increasing both gas-turbine and steam-turbine performance.

The primary potential advantages of a fluidized bed boiler power plant are:

- Reduced volume and modular construction. Because combustion rates are more intense in fluidized beds than in the fire box of a pulverized fuel furnace, and because the heat transfer surface can be placed in the bed, fluidized bed boilers are more compact than conventional coal-fired boilers. Pressurized boiler modules can be fabricated in shops and installed at a power plant site. Considerable economies are possible in the fabrication and erection of pressurized fluidized bed combustion boilers.

- Reduced heat transfer surface requirements. Because heat transfer coefficients are an order of magnitude greater in fluidized beds than in the fire box of a conventional boiler, less heat transfer surface is required in the boiler. In a pressurized boiler, less heat is extracted from the combustion gases after they leave the fluidized bed because they are cooled by expansion in the gas turbine. Further large reductions in heat transfer surface are thus possible. The heat transfer surface in the pressurized boiler is ∿ 80% less than the surface in a conventional p.f. boiler.

- Reduced steam tube and turbine blade corrosion/erosion and fouling. Because the fluidized bed boiler operates at a maximum combustion temperature far below that in a conventional boiler, volatilization of alkali metal compounds and fusion of ash is reduced or eliminated. Sulfur and vanadium compounds are removed from the combustion gases by the sorbent. The corrosion/erosion and fouling of steam tubes and turbine blades is thus minimized. Under these conditions, higher steam temperatures and pressures may become economically feasible,and greater efficiency in power generation may be achieved. Somewhat greater efficiencies can also be achieved in pressurized fluidized bed combustion by using gas turbines with high inlet temperatures.

- Reduced fuel costs and increased flexibility. Because fluidized beds can readily burn crushed coal (fine grinding is not required), coal with a high ash content, and a variety of miscellaneous combustibles (from sewage sludge, municipal solid wastes, paper mill liquid wastes, and oily wastes to residual oil and natural gas), boilers using such beds can utilize cheap fuels and a wide variety of fuels to generate power and steam.

- Reduced emissions of SO_2 and NO_x. Because a limestone/dolomite sorbent can be utilized in a fluidized bed combustor, SO_2 reductions of 90 to 95% can be economically achieved. The low combustion temperature at which the bed operates minimizes the formation of NO_x by fixation of atmospheric nitrogen. Production of NO_x by oxidation of nitrogen in the fuel is minimized by operating the bed at high pressure. Compliance with NO_x emission regulations at atmospheric pressure will require design and/or operating modifications to the boiler.

Several characteristics of a pressurized fluidized bed boiler must be demonstrated: operation of deep beds with internals, adequate particulate removal for reliable gas-turbine operation, and sorbent regeneration of high stone utilization to permit once-through operation.

Pressurized fluid bed boiler apparatus and support facilities have been operated to supply information on:

- Combustion and combustion efficiency
  - C carry-over
  - Burning above bed -- C solids and gases
- Pollution abatement
  - SO_2
    - Removal
    - Regeneration
    - Recovery
  - NO_x reduction
  - Particulate
    - Formation, ash, and sorbent attrition
    - Removal
- Heat generation and transfer
  - Combustion in deep beds
  - Temperature distribution
  - Heat transfer coefficient distribution
- Reactant feed and distribution
  - Fuel
  - Sorbent
  - Air
- Materials
  - Steam tube
  - Turbine blade

This information has been and is being obtained on different types of experimental apparatus and on different scales. A summary of available and planned pressurized fluidized bed boiler apparatus is summarized in Table 1.

TABLE 1

PRESSURIZED FLUIDIZED BED BOILER APPARATUS

Type	Location	Capacity		Operating Limitations			Purpose	Status
		Diameter	Lb coal/hr	Temperature °F	Pressure psi	Gas Velocity fps		
Special Purpose								
TG	Westinghouse	-	-	2200	450	-	kinetic studies on sulfur removal/ regeneration	operating
TG	CCNY	-	-					
Fluid bed	Argonne	2 inch	-	>2000	150			operating
Fixed bed	Esso	1 inch	-	>2000	150	5		operated
Cold models	Westinghouse	1-1/2"x9"	-	ambient	ambient	1-40	alternative concepts	operating
		4 inch	-	ambient	150	up to 6	fluidization and solids handling	operating
	Esso	4 inch?	-	ambient	40	up to 10	fluidization and solids handling	
Pilot Plants								
Semi-batch	Argonne	6 inch	60	1900	135		sulfur removal/ combustion	operating
	Argonne	3 inch	-	2100	135		regeneration	operating
Semi-batch	Esso	3 inch	-	2200	150	5	regeneration	operating
	Esso						combustion/sulfur removal	Nov. 1972?
Continuous	Esso	5 inch	-	2000	150	5	regeneration	Jan. 1974
		12.5 inch	480	1700	150	10	combustion/sulfur removal	Jan. 1974
Semi-batch	BCURA	2'x4'	~400	1500	90	2	combustion/sulfur removal	operated 1969-1971 1973-
Development Plant								
	?	5'x7'	nominal 22,000	2000	225	15	data for demonstration plant	preliminary design, Dec. 1972

4. DEVELOPMENT PLANT DESIGN

The pressurized fluid bed combustion boiler program at BCURA[*] demonstrated the feasibility of pressurized fluid bed combustion in an 8 ft^2 combustor. Specifically, it demonstrated:

- SO_2 emissions of $\leq$ 0.7 lb/10^6 Btu
- NO_x emissions of 0.07-0.2 lb $NO_2/10^6$ Btu
- Coal feeding at 3-1/2 and 5 atmospheres
- Continuous operation -- runs up to 350 hours
- No erosion or corrosion of gas-turbine blade test passages after 200-hour tests
- Particulate removal at $\sim$ 1500°F and 5 atmospheres by cyclones proved adequate for turbine blade tests
- Adequate boiler tube materials for commercial applications
- Bed operation with horizontal tube bundle.

Commercial boiler design operating conditions require that the bed be operated at higher gas velocity, higher bed pressure, higher temperature, and with a deeper bed than the BCURA unit. A development plant is required to investigate the design, construction, and performance of the proposed boiler plant equipment system design at the proposed operating conditions so that commercial feasibility might be assessed. Several features require a large plant to evaluate the design and performance:

- Operation of deep beds (10 to 20 ft) with horizontal tube bundles and headers with aspect ratios $< \sim 2.5$
- Heat generation and temperature distributions
- Coal feeding requirements and sorbent distribution in a large bed ($\sim$ 35 ft^2)
- Particulate control equipment performance
- Heat transfer surface configuration and materials requirements

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[*] British Coal Utilization Research Association.

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- Gas-turbine blade materials and component life
- Disengaging height design criteria
- Operational techniques -- start-up, shutdown, load follow, stability
- Long-term operability at design and operating conditions
- Fabrication, maintenance, and repair of boiler and auxiliary components.

The plant is also required to confirm, on larger scale, results obtained in laboratory and bench apparatus and in pilot plants:

- Emissions -- SO_2, NO, CO, C, alkali metals
- Combustion efficiencies
- Sorbent utilization
- Sorbent attrition
- Air distribution
- Boiler tube materials
- Particle carry-over and the sources.

Further, only a full-scale unit will provide solutions to the following problems:

- Erosion that may occur due to full-scale tube configurations
- Feed point location distribution requirements for coal and dolomite into a full-size fluidized bed (number of feed points and their location)
- Thermal inertia effects in turndown and start-up of a full-scale module
- Physical arrangement for maintenance access (tube repair, coil replacement, instrument replacement, etc.)
- Determination of shop-fabrication methods and costs, and the associated shipping protection requirements

- Mechanical design methods suitable for tube bundle support, grid plate support, differential expansion of water-wall penetrations, etc.
- Investigation of tube vibration over the long span tube lengths only utilizable in a full-scale module
- Determination of field-erection methods and costs, not obtainable from a small-scale unit
- Determination of various unusual operating effects on the full-scale module mechanical design. Conditions created by an emergency shutdown of the turboexpander or a low-flow surge of the centrifugal air supply compressor would be used to test the design adequacy of the full-scale module.
- Investigation of optimum space utilization and heat transfer surface configuration within the fluidized bed can best be proved out by testing alternative tube bundle designs in the full-scale module.

Other objectives which are being considered for the facility include:

- Need to test sulfur recovery system
- Feasibility of studying advanced concepts -- higher steam temperature and pressure, higher gas-turbine temperatures, circulating beds, deeper beds (30 ft), higher pressures
- Feasibility of expanding to multiple bed operation.

The development plant is planned so that sufficient information can be obtained to design, build, and operate a demonstration plant of 150 to 300 MW. Appendix I provides the complete design and estimates as prepared for Westinghouse by Foster Wheeler, Inc.

4.1 DESIGN BASIS

The development plant design is based on the objectives outlined for it and for the commercial plant design. For the plant to provide sufficient information to design, build, and operate a demonstration power plant, the unit must be large enough to:

- Test multiple point coal feeding
- Avoid untypical height/diameter ratios with bed operation
- Test proposed heat transfer surface configurations
- Test effect of bed emissions on gas-turbine performance.

These design characteristics can be met by constructing a fluidized bed unit with a capacity equivalent to one bed in a 75- to 100-MW_e module.[1] The range of operating conditions and design criteria established for the plant are summarized in Table 2.

The location of the plant is an important consideration, since large quantities of coal and water are required and large quantities of steam are produced. Several advantages could be achieved by locating the development plant on an existing power plant site:

- Availability of coal-handling, water preparation, and solids disposal facilities
- Existing plant would dispose of steam
- Superheat and reheat steam generation can be studied by using bleed stream from existing plant
- Utility partnership would minimize site development and development time, and provide plant utilities and maintenance facilities.

Thus, the preferred location option would be adjacent to a large power plant where appropriate tie-ins could be effected for the supply of utilities, coal, boiler feedwater, and saturated steam; and the return of superheated steam. Such a location would simplify and reduce the cost of installation of the developmental test boiler.

If it is not possible to locate adjacent to a utility, then it will be necessary to install water purification equipment, as well as boiler feedwater storage, condensers for steam, and adequate boiler feedwater pumps. In addition, various auxiliaries such as instrument air, cooling towers, and a packaged boiler would be required at an independent site.

TABLE 2

DESIGN BASIS FOR PRESSURIZED FLUIDIZED BED BOILER DEVELOPMENT PLANT

Coal	Pittsburgh No. 8 (4.3% S)
Sulfur Removal Sorbent	dolomite (1337)
Pressure	1-20 atm
Temperature	1500-2000°F
Gas Velocity	6-15 fps
Bed Area	∿ 35 ft^2
Bed Depth	4-30 ft
Ca/S	1-6 for once-through 2-10 for regeneration
Heat Transfer Coefficient	50 Btu/hr-ft^2-°F
Particulate Carry-over	10-30 grains/scf
Particle Size	
Coal	-1/4" x 0
Dolomite	-1/4" x 0 or 1/4" x 28 mesh
Site	existing power plant
Air supply	separate air compressor, motor drive
Excess air	> 100% capability
Air preheat	to 600-850°F
Feedwater temperature	to 230-500°F
Heat transfer surface	capability for testing water walls, preheat, evaporation, and superheat tube bundles

4.2 FLOW DIAGRAM

Figure 3 is a simplified flow diagram of the pressurized fluid bed combustion boiler development plant. The plant is adjacent to a large power plant to which it has access to provide interfaces with the coal, water, steam, waste stone, and utilities. Engineering flow diagrams are shown in Figures 4, 5, and 6.

4.3 MATERIAL AND ENERGY BALANCE

The material balance and operating conditions for the development plant at the projected 100% load nominal design condition are presented in Tables 3 and 4. A heat balance for the nominal design is presented in Table 5.

4.4 BOILER MODULE DESIGN

The pressurized fluidized bed boiler for the development plant comprises a single bed of the four required for an 80 MW module.[1] The steam generator is a water-walled box formed of vertical 1-1/2 in. tubing within a 12-ft diameter pressure shell approximately 78 feet tall designed for 320 psig pressure. The combustor has a rectangular cross-section 5 ft x 7 ft. The design of the pressurized fluid bed boiler is shown in Figures 7 and 8. The air distributor plate at the bottom of the box can be raised by as much as 4 feet to vary the distance between the base of the bed and the bottom of the horizontal steam tubes submerged in the bed. These steam tubes form sets of parallel vertical platens of serpentine bends filling the cross section of the bed. Three sets of platens or heat exchange bundles are provided so that three different bed heights (and three different amounts of heat transfer surface in the bed) can be provided.

Two tube bundle designs were developed. One, shown in Figure 7, supports the tube bundle from headers located in the high-temperature gas pass. Spare bundles are used to study different bed heights. This design minimizes the number of connections which provides

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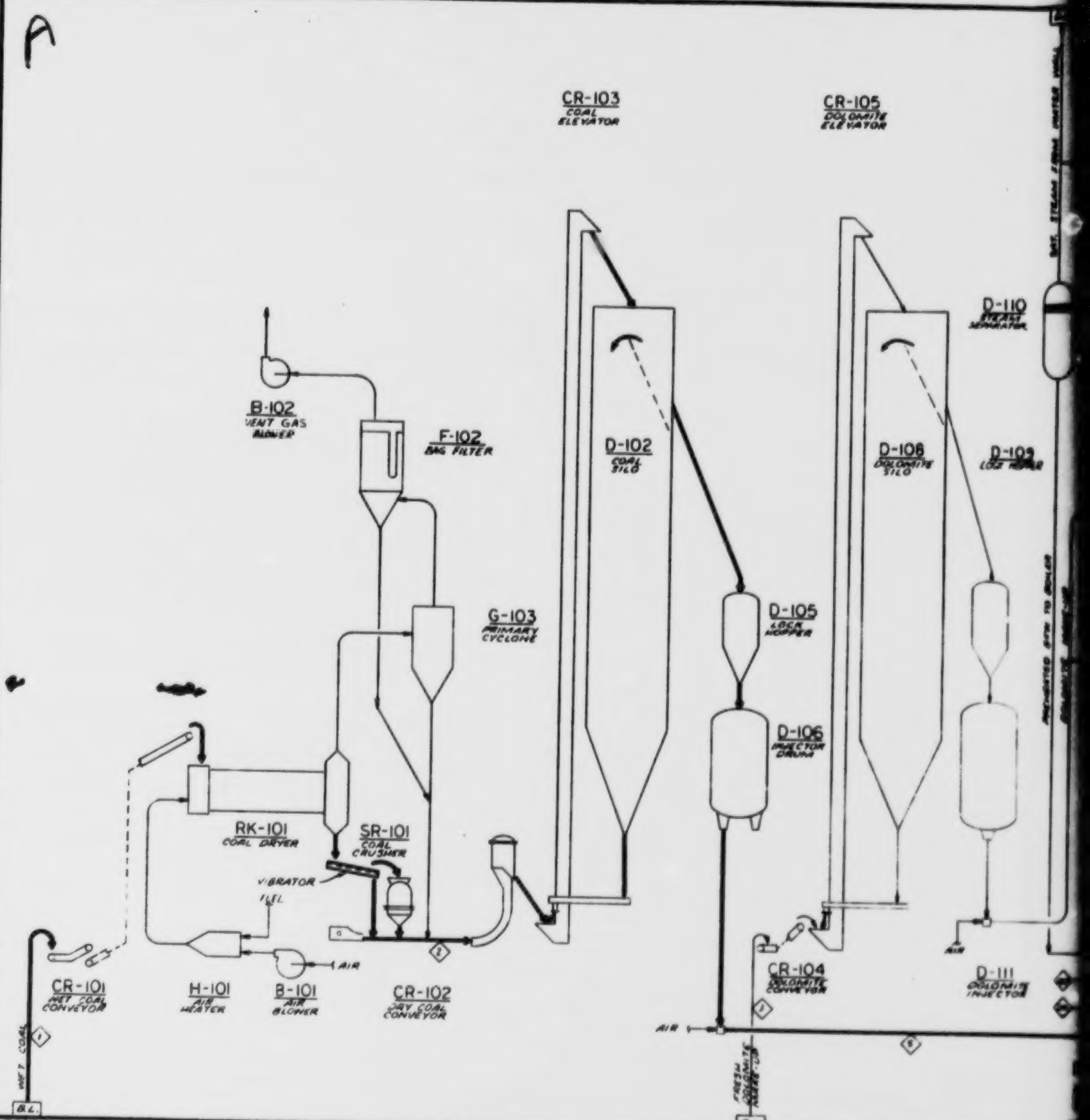


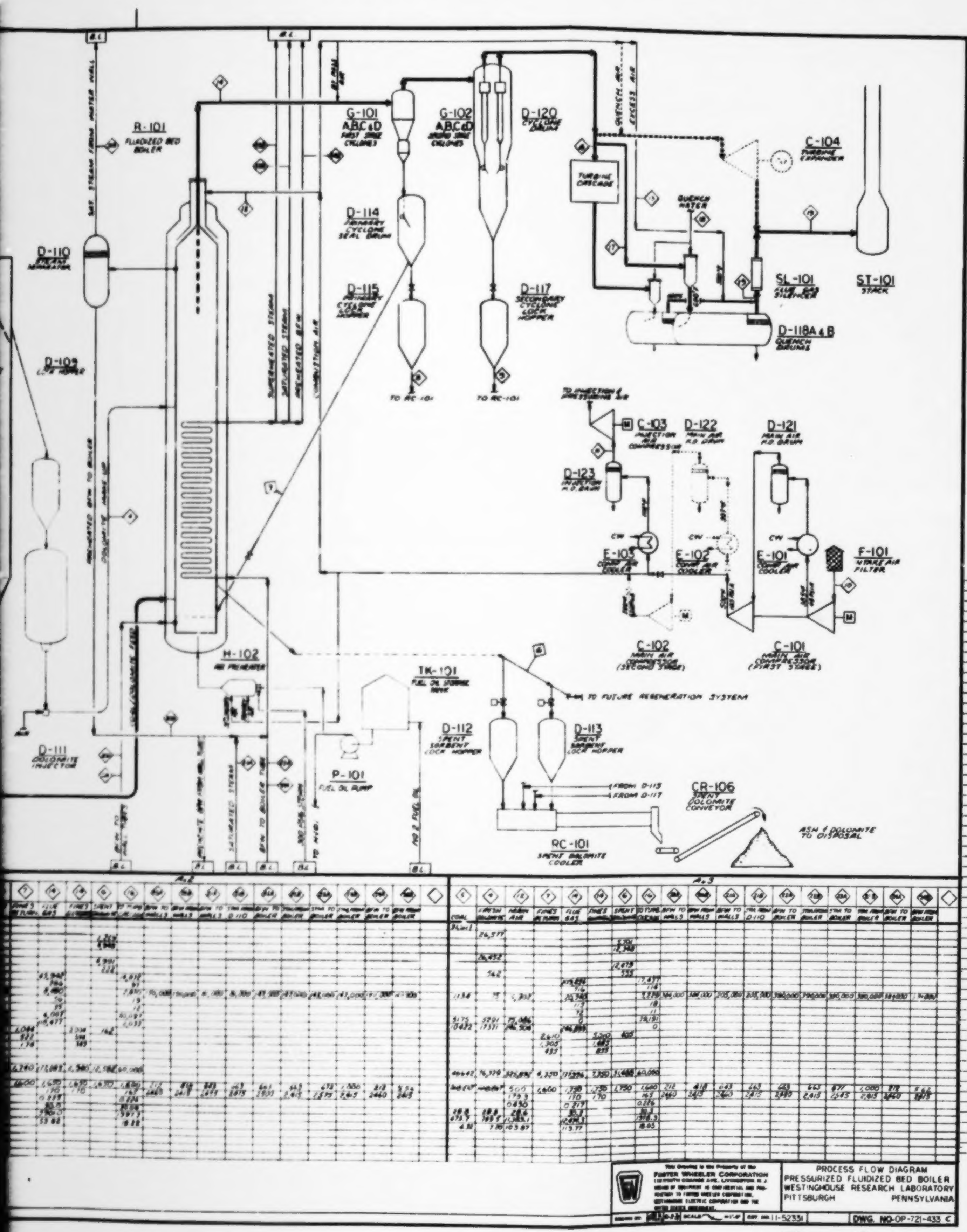
CASE		A,1																	
STREAM Nº		6	4	12	7	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
COMPONENT	STREAM	COAL	FRESH DOLOMITE	MAIN AIR	FINES RETURN	FLUE GAS	FINES QUENCH	SPENT DOLOMITE	TO TURBINE CASCADE	BFW TO WALLS	STM FROM WALLS	BFW TO WALLS	STM FROM D-110	BFW TO BOILER	STM FROM BOILER	STM TO BOILER	STM FROM BOILER	BFW TO BOILER	STM FROM BOILER	
COAL	LB/HR	21,270																		
CaCO₃	LB/HR		17,718																	
CaSO₄	LB/HR							3,780												
CaO	LB/HR							8,241												
MgCO₃	LB/HR		7,635																	
MgO	LB/HR							8,318												
INERTS	LB/HR		375					310												
CO₂	LB/HR					73,236			16,058											
CO	LB/HR					677			105											
H₂O	LB/HR	771	75	3,155		3,667			3085	250,000	250,000	133,000	33,000	260,000	260,000	275,000	275,000	250,000	250,000	
SO₂	LB/HR					86			13											
NO	LB/HR					56			12											
O₂	LB/HR	3.75	5281	55,063		5,006			1,097											
N₂	LB/HR	3422	17371	180,770		181,031			39,680											
ASH	LB/HR				1,700		338													
CARBON	LB/HR				870		390	230												
DOLOMITE	LB/HR				230		570													
TOTAL - LBS/HR		31,642	30,465	238,988	2,800	272,787	1,300	20,879	60,000											
TEMP. - °F		AMBIENT	AMBIENT	860	1600	1650	1650	1650	1,600	212	618	683	663	663	663	670	1,000	212	374	
PRESSURE - PSIA				176.4		170	170		165	2503	2415	1455	2415	2490	2415	2,540	2415	2435	2415	
DENSITY - LBS/CF				0.882		0.221			0.223											
MOL. WT. (EX SOLIDS)		28.8	28.8	28.6		30.2			30.2											
MOL./HR (EX SOLIDS)		673.7	789.3	8351.9		9073.6			1986.8											
MMSCFD (EX SOLID)		4.32	7.20	76.17		82.77			18.12											
SP. GR. (LIQ.)																				
GPM (HOT)																				

STREAM Nº	6	4	12	7	14	[illegible]	[illegible]
	COAL	FRESH DOLOMITE	MAIN AIR	FINES RETURN	FLUE GAS	FINES QUENCH	SPENT
COAL	12,764						
CaCO₃		10,631					
CaSO₄							[illegible]
CaO							
MgCO₃		5,391					
MgO							[illegible]
INERTS		228					
CO₂					63,948		
CO					786		
H₂O	48	14	2,065		8,480		
SO₂					56		
NO					35		
O₂	3175	5761	36,061		4,007		
N₂	10622	17371	118,328		118,677		
ASH				1,044		2,006	[illegible]
CARBON				522		380	
DOLOMITE				174		307	
TOTAL - LBS/HR	20,948	46,176	158,420	1,740	172,003	2,300	[illegible]
TEMP. - °F	AMBIENT	AMBIENT	500	1600	1650	1650	1650
PRESSURE - PSIA			173		170	170	
DENSITY - LBS/CF			0.490		0.228		
MOL. WT. (EX SOLIDS)	[illegible]	[illegible]	28.6		30.0		
MOL./HR (EX SOLIDS)	[illegible]	[illegible]	5466.7		5900.0		
MMSCFD (EX SOLID)	4.32	7.20	49.86		53.69		
SP. GR. (LIQ.)							
GPM (HOT)							

NOTES:

1. STREAM Nº 6 COAL FEED RATE REPRESENTS AVERAGED THROUGPUT OVER 24 HOUR PERIOD.
2. STREAM Nº 16 FLUE GAS TO C-104 EXCLUDES QUENCH AIR IF REQUIRED.
3. FOR STREAM DATA NOT LISTED IN THIS DWG. CAN BE FOUND IN TABLES FOR MATERIAL BALANCE.
4. EQUIPMENT IN DOTTED LINES REFERS TO FUTURE FACILITIES.

B



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110 SOUTH ORANGE AVE., LIVINGSTON, N.J.

PROCESS FLOW DIAGRAM
PRESSURIZED FLUIDIZED BED BOILER
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PENNSYLVANIA

DWG. NO. OP-721-433 C

Figure 3

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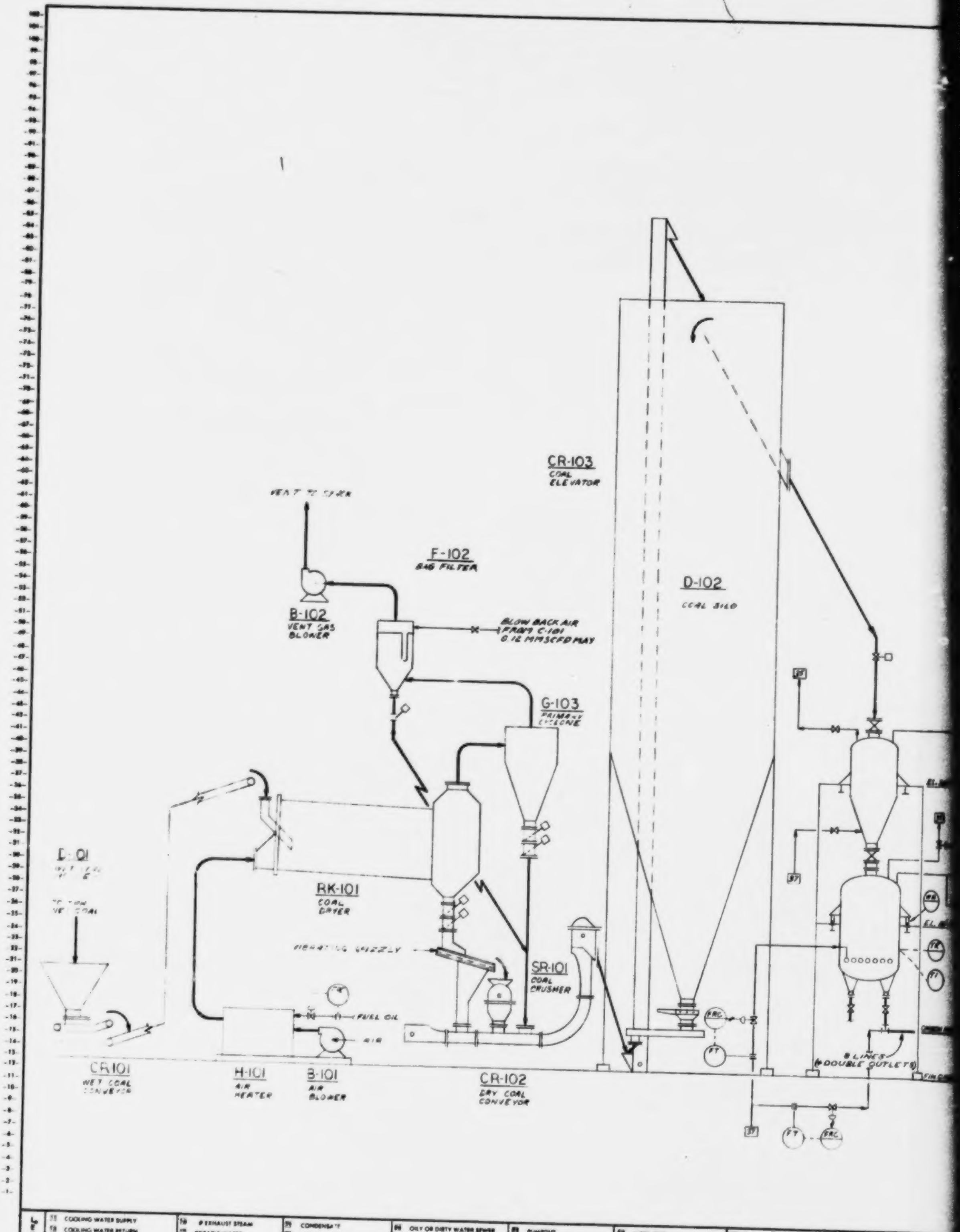

LEGEND
- COOLING WATER SUPPLY
- COOLING WATER RETURN
- # H.P. STEAM
- # STEAM (INTERMEDIATE PRESS.)
- # L.P. STEAM
- # EXHAUST STEAM
- POTABLE WATER
- PLANT AIR
- INSTRUMENT AIR
- H.P. CONDENSATE
- CONDENSATE
- TREATED WATER
- FUEL OIL
- FUEL GAS
- CLEAN WATER SEWER
- OILY OR DIRTY WATER SEWER
- PROCESS SEWER
- SANITARY SEWER
- FIRE WATER
- FLUSHING OIL
- PUMPOUT
- PURGE GAS
- BLOWDOWN
- FLARE
- TO ATMOSPHERE
- INERT GAS
- INJECTION AIR

ITEM NO			CR-10	CR 02	CR-103	CR-104	CR-105	H-101	B-101	B-102
SERVICE			WET COAL CONVEYOR	DRY COAL CONVEYOR	COAL ELEVATOR	DOLOMITE CONVEYOR	DOLOMITE ELEVATOR	AIR HEATER	AIR BLOWER	WET GAS BLOWER
MATERIAL			CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL
CORR. ALL.								REFRACTORY LINED	6"	9"
INSULATION										
REVISIONS										

ITEM NO						RK-101
SERVICE						COAL DRYER
MATERIAL						CARBON ST
CORR ALL						1/8"
INSULATION						

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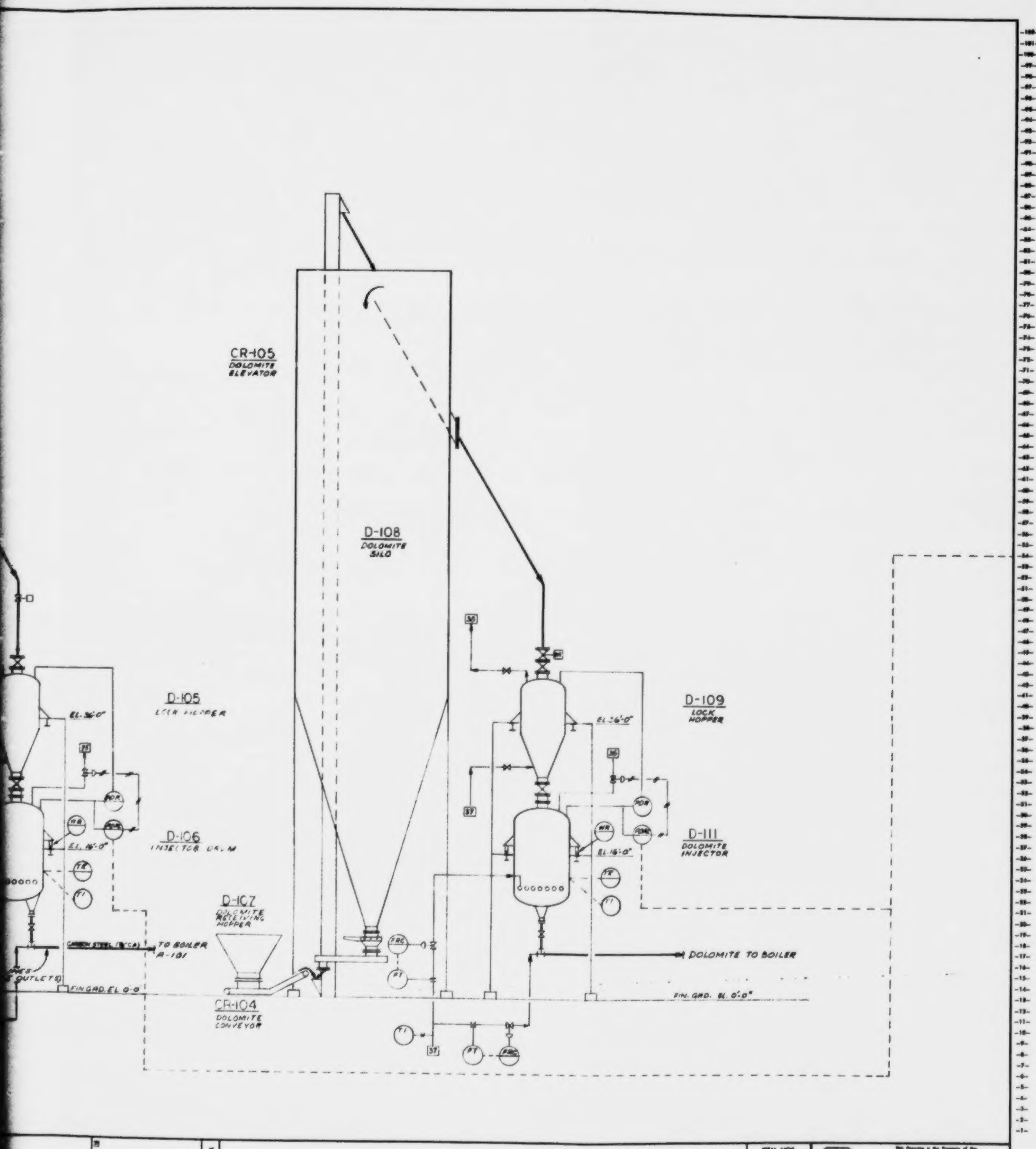

NOTES

RK-101	SR-101	F-102	G-103	ITEM NO.	D-101	D-102	D-105	D-106	D-107	D-108	D-109	D-111
COAL DRYER	COAL CRUSHER	BAG FILTER	PRIMARY CYCLONE	SERVICE	WET COAL HOPPER	COAL SILO	LOCK HOPPER	INJECTOR DRUM	DOLOMITE RECEIVING HOPPER	DOLOMITE SILO	LOCK HOPPER	DOLOMITE INJECTOR
				SIZE								
				DES. PRESS-TEMP								
				OPER. PRESS-TEMP								
CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	MATERIAL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL
1/16"		1/16"	1/16"	CORR. ALL.	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"
				INSULATION								

ITEM NOS. THIS DWG.

B-101	
B-102	D-108
CR-101	D-109
CR-102	D-111
CR-103	F-102
CR-104	G-103
CR-105	H-101
D-101	RK-101
D-102	SR-101
D-105	
D-106	
D-107	

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ENGINEERING FLOW DIAGRAM
PROPOSED COAL PREPARATION AND
INJECTION SYSTEM
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PENNSYLVANIA

EST. NO.
CONTRACT NUMBER 11-52331
DRAWN BY ZC 8-29-72 SH. 1 OF 3
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Figure 4

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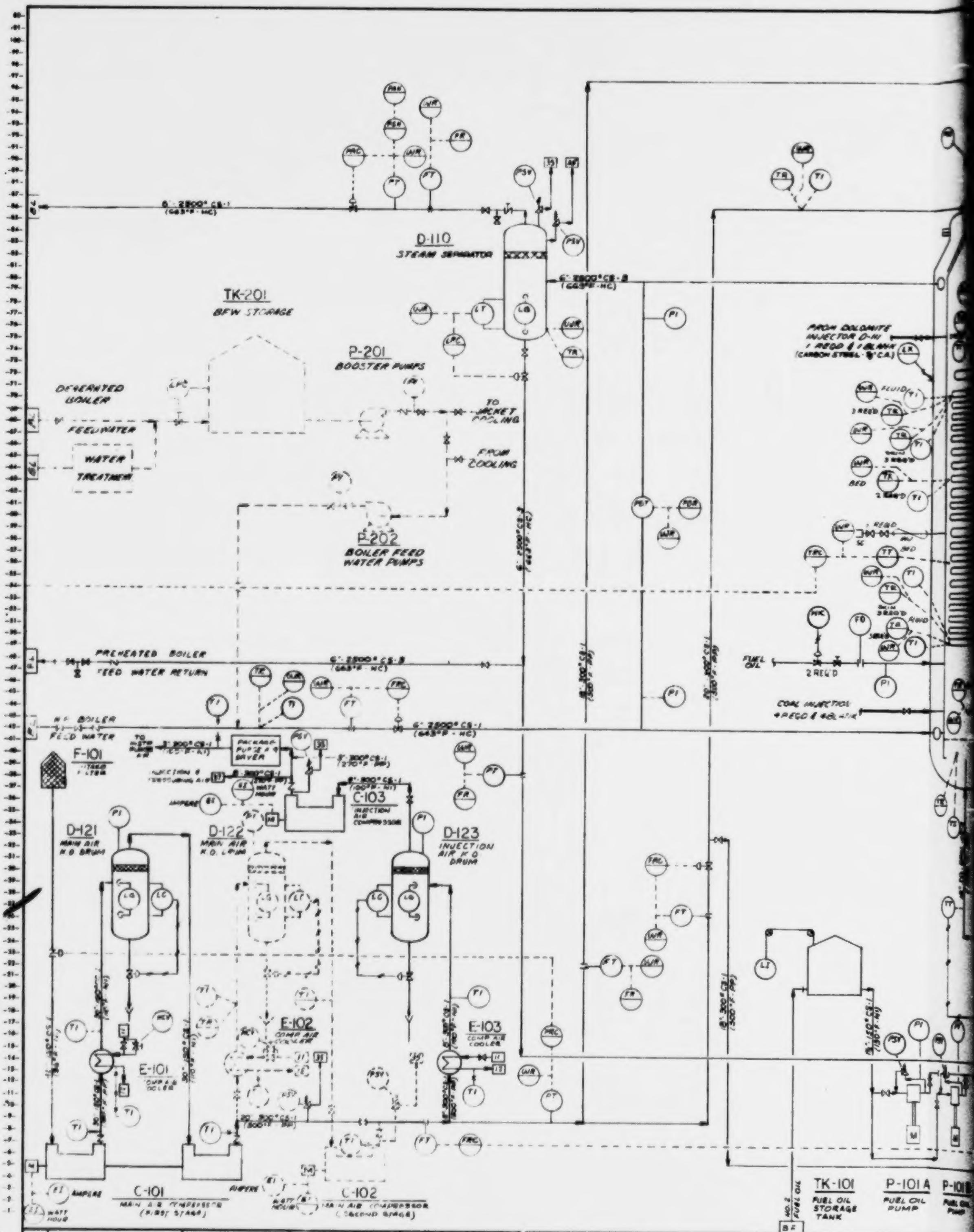

LEGEND

- CW COOLING WATER SUPPLY
- CR COOLING WATER RETURN
- SH # H.P. STEAM
- SM # STEAM (INTERMEDIATE PRESS.)
- SL # L.P. STEAM
- # EXHAUST STEAM
- POTABLE WATER
- PLANT AIR
- INSTRUMENT AIR
- H.P. CONDENSATE
- CONDENSATE
- TREATED WATER
- FUEL OIL
- FUEL GAS
- CLEAN WATER SEWER
- OILY OR DIRTY WATER SEWER
- PROCESS SEWER
- SANITARY SEWER
- FIRE WATER
- FLUSHING OIL
- PUMPOUT
- PURGE GAS
- BLOWDOWN
- FLARE
- TO ATMOSPHERE
- INERT GAS
- INJECTION AIR

ITEM NO	P-101A	P-101B							C-101	C-103
SERVICE	FUEL OIL PUMP	FUEL OIL PUMP							MAIN AIR COMPRESSOR	INJECTION AIR COMPRESSOR
S.G. AT P.T.										
DES. G.P.M. AT P.T.	–	SPARE							121.5 MMSCFD	17.0 MMSCFD
DES. DIFF. PSI	450	FOR							170.3	480.7
MAX DISCH PSIG	450	P-101A							85 PSIA	465 PSIA
MATERIAL	CARB. ST. (1/8 CA)								CARB. STL. (1/8"CA)	CARB. STL. (1/8"CA)
INSULATION	NI								NI	NI

ITEM NO	E-101	E-103				
SERVICE	COMPRESSOR AIR COOLER	COMPRESSOR AIR COOLER				
SHELL DES. P & T	75# @ 435°F	200# @ 600°F				
TUBE DES. P & T	75# @ 160°F	75# @ 180°F				
SURFACE	9700 SQ FT	964 SQ FT				
MAT'L SHELL	CARB. STL. (1/8"CA)	CARB. STL. (1/8"CA)				
MAT'L TUBE	CARB. STL. (1/8"CA)	CARB. STL. (1/8"CA)				
INSULATION	NI	NI				

REVISIONS

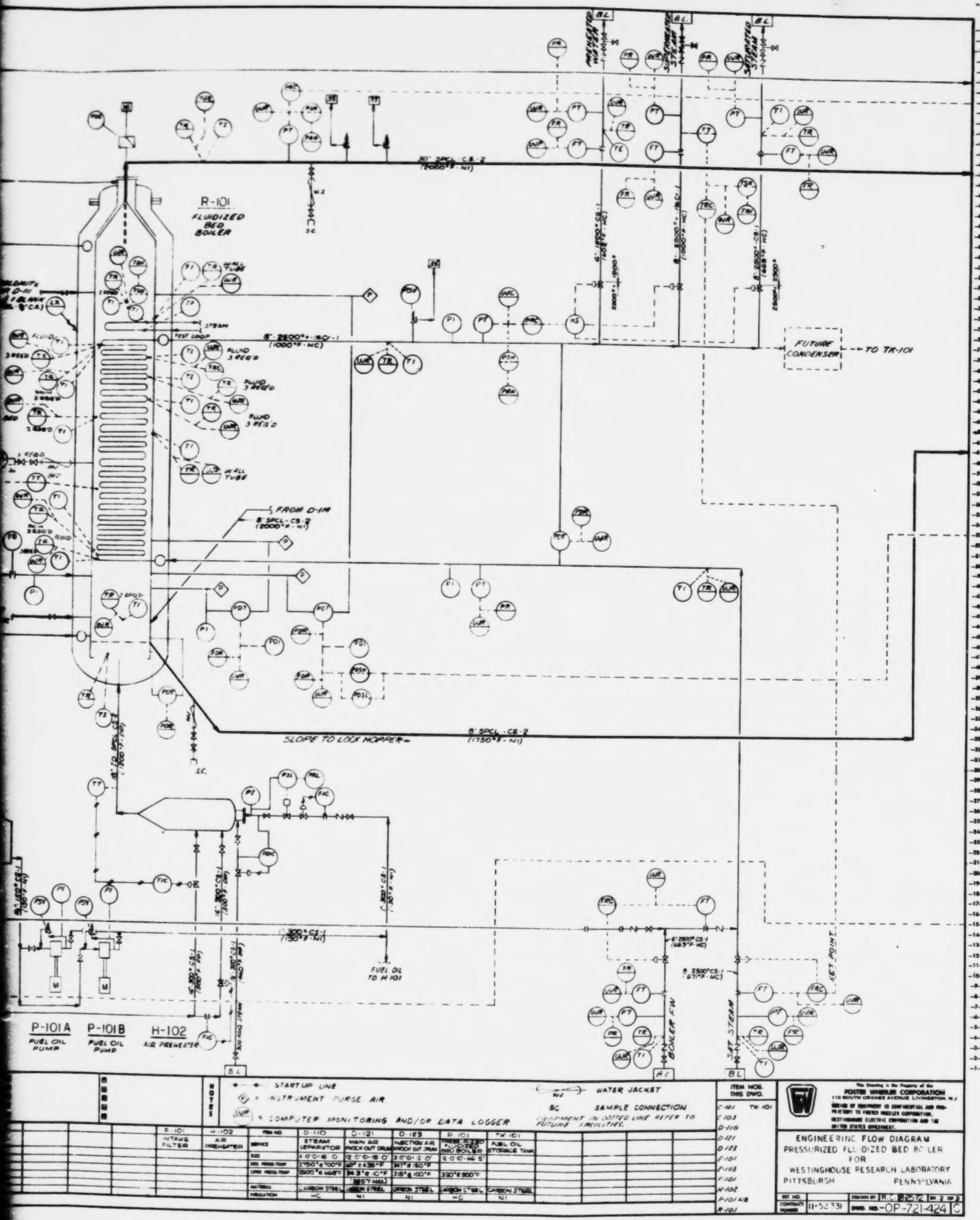
R-101
FLUIDIZED BED BOILER
8" 2500" - 1SC - 1 (1000°F - HC)
FUTURE CONDENSER
TO TK-101
FROM D-121
SLOPE TO LOCK HOPPER
FUEL OIL TO H-101
BOILER FW
SAT STEAM
SET POINT
P-101A
FUEL OIL PUMP
P-101B
FUEL OIL PUMP
H-102
AIR PREHEATER
STARTUP LINE
= INSTRUMENT PURGE AIR
= COMPUTER MONITORING AND/OR DATA LOGGER
WATER JACKET
SC SAMPLE CONNECTION
EQUIPMENT IN DOTTED LINE REFER TO FUTURE FACILITIES.
F-101 INTAKE FILTER
H-102 AIR PREHEATER
D-110 STEAM SEPARATOR
D-121 MAIN AIR KNOCK OUT DRUM
D-123 INJECTION AIR KNOCK OUT DRUM
R-101 PRESSURIZED FLUIDIZED BED BOILER
TK-101 FUEL OIL STORAGE TANK
FOSTER WHEELER CORPORATION
110 SOUTH ORANGE AVENUE, LIVINGSTON, N.J.
ENGINEERING FLOW DIAGRAM
PRESSURIZED FLUIDIZED BED BOILER
FOR
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PENNSYLVANIA
11-52331
OP-721-424 C

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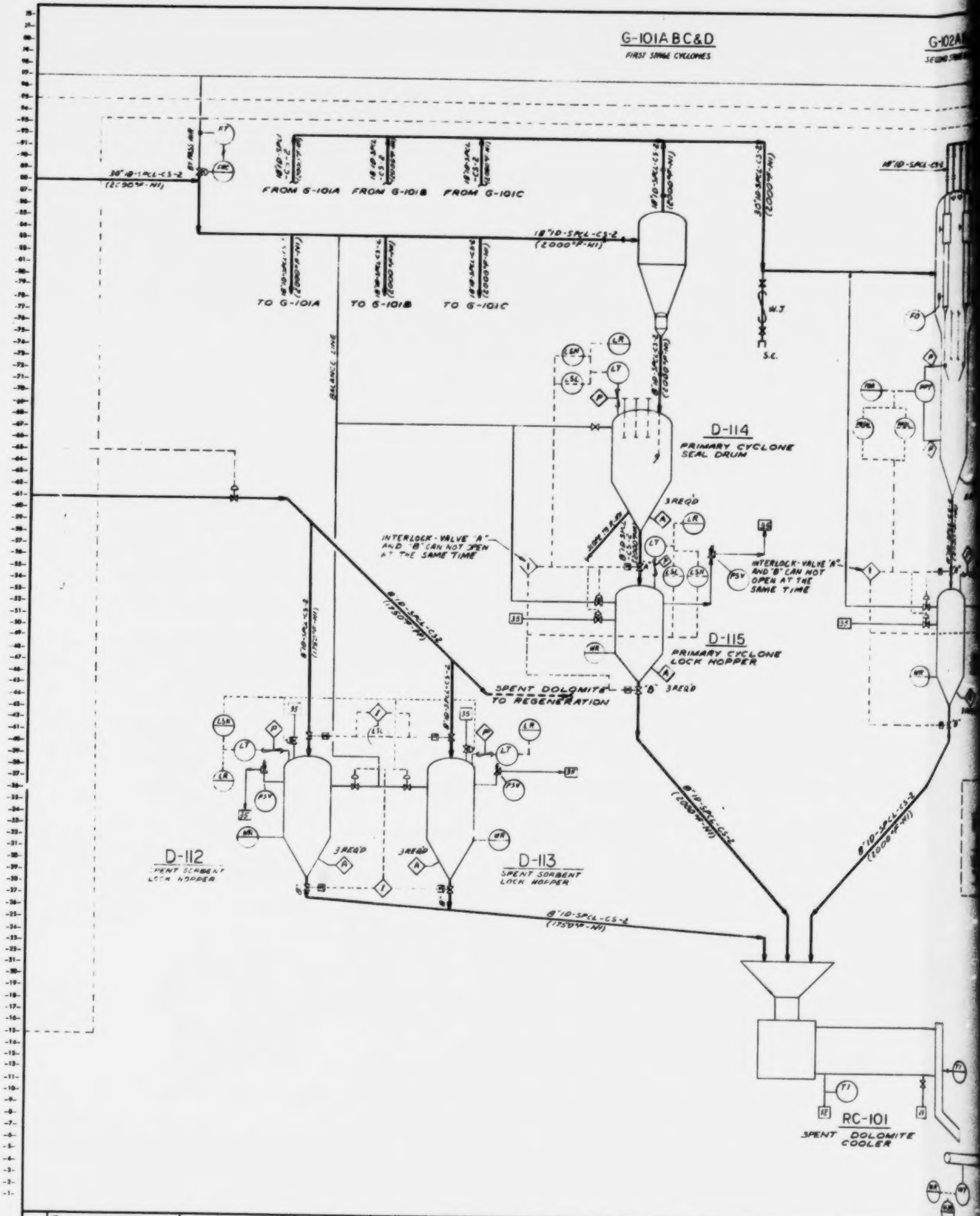
Figure 5

A


G-101A B C&D
FIRST STAGE CYCLONES
G-102A
30" ID-SPCL-CS-2 (2000°F-NI)
FROM G-101A
FROM G-101B
FROM G-101C
TO G-101A
TO G-101B
TO G-101C
18" ID-SPCL-CS-2 (2000°F-NI)
30" ID-SPCL-CS-2 (2000°F-NI)
18" ID-SPCL-CS-2
BALANCE LINE
W.J
S.C.
FO
LR
LT
LSH
LSL
P
PSV
WR
D-114
PRIMARY CYCLONE SEAL DRUM
3REQ'D
A
INTERLOCK - VALVE "A" AND "B" CAN NOT OPEN AT THE SAME TIME
8" ID-SPCL-CS-2 (2000°F-NI)
35
D-115
PRIMARY CYCLONE LOCK HOPPER
"A"
"B"
8" ID-SPCL-CS-2 (1750°F-NI)
SPENT DOLOMITE TO REGENERATION
D-112
SPENT SORBENT LOCK HOPPER
D-113
SPENT SORBENT LOCK HOPPER
I
8" ID-SPCL-CS-2 (2000°F-NI)
RC-101
SPENT DOLOMITE COOLER
TI

LEGEND

COOLING WATER SUPPLY
COOLING WATER RETURN
H P STEAM
STEAM (INTERMEDIATE PRESS.)
L P STEAM
EXHAUST STEAM
POTABLE WATER
PLANT AIR
INSTRUMENT AIR
H P CONDENSATE
CONDENSATE
TREATED WATER
FUEL OIL
FUEL GAS
CLEAN WATER SEWER
OILY OR DIRTY WATER SEWER
PROCESS SEWER
SANITARY SEWER
FIRE WATER
FLUSHING OIL
PUMPOUT
PURGE GAS
BLOWDOWN
FLARE
TO ATMOSPHERE
INERT GAS
INJECTION AIR LINE

ITEM NO									SL-101	CR-106
SERVICE									FLUE GAS SILENCER	SPENT DOLOMITE CONVEYOR
SG AT PT										
DES GPM AT PT										
DES DIFF PSI										
MAX DISCH PSIG										
MATERIAL										
INSULATION									CARB STL (CA)	CARBON STEEL
REVISIONS										

ITEM NO.							
SERVICE							
SHELL DES. P. & T.							
TUBE DES. P. & T.							
SURFACE							
MATL. SHELL							
MATL. TUBE							
INSULATION							

FORM 130 29C REV

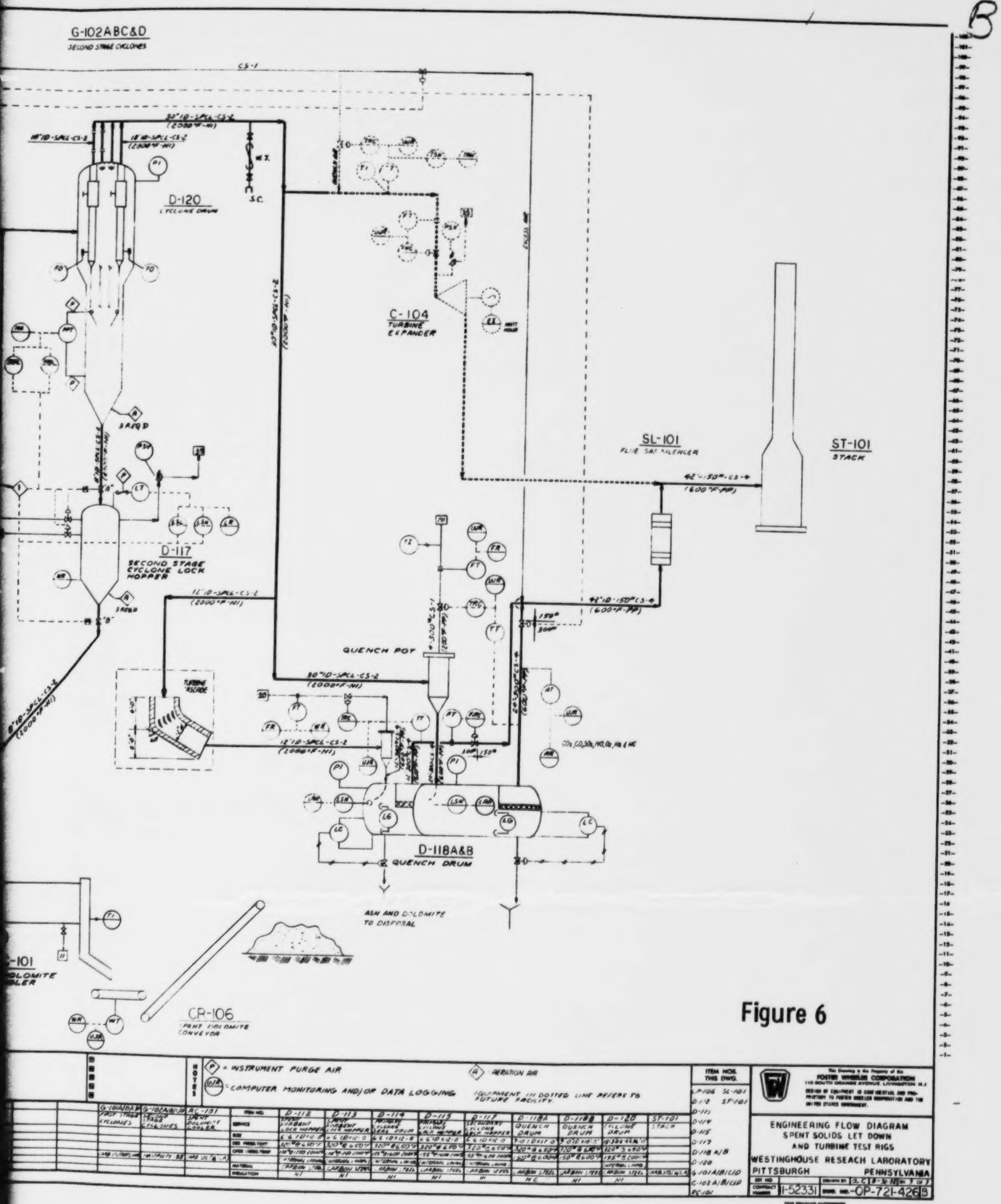


Figure 6

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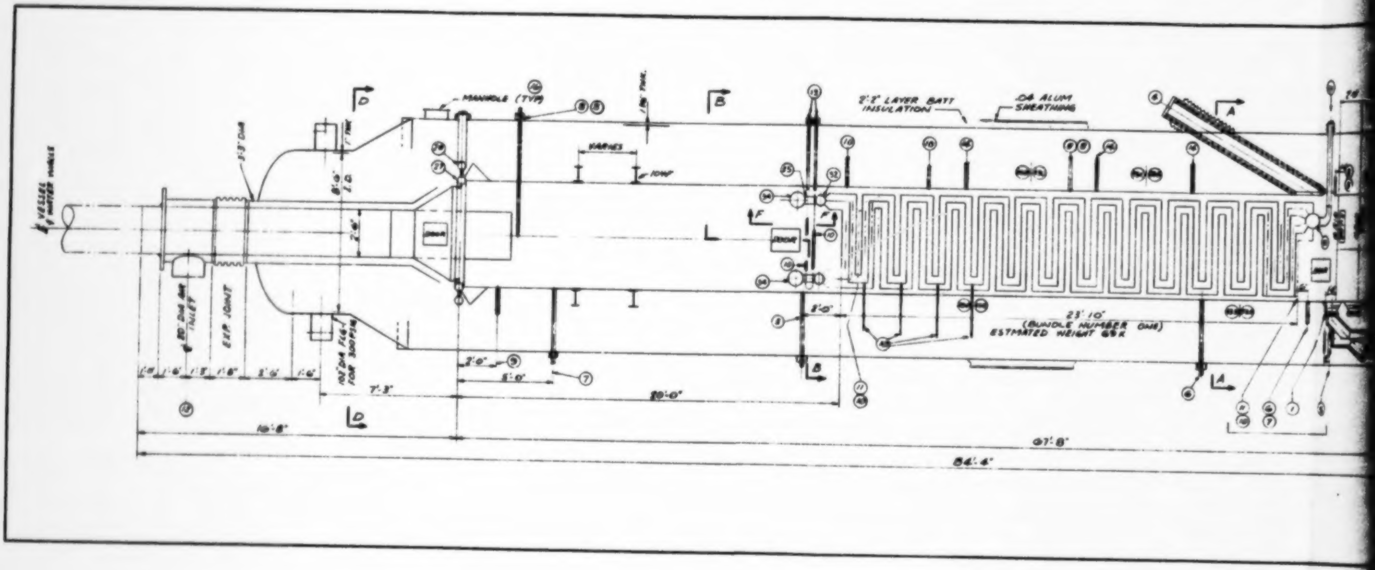
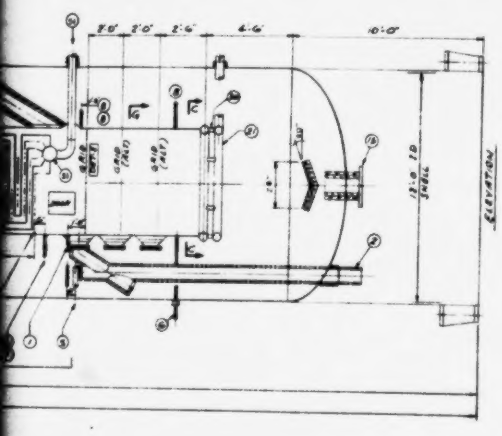
A



℄ VESSEL & WATER MAINS
3'-3" DIA
MANHOLE (TYP)
1" THK
1/8" THK
VARIES
10WF
8'-0" I.D.
2'-6"
20" DIA AIR INLET
EXP. JOINT
10 1/2" DIA FLG. FOR 300 PSIG
1'-0"
1'-6"
1'-3"
1'-8"
2'-0"
1'-0"
7'-3"
2'-0"
5'-0"
20'-0"
16'-8"
D
B
F
2'-2" LAYER BATT INSULATION
.04 ALUM SHEATHING
A
2'-0"
23'-10"
(BUNDLE NUMBER ONE)
ESTIMATED WEIGHT 65K
67'-8"
84'-4"
⑤
⑦
⑪

B



ITEM	DESCRIPTION	REQ'D PER ITEM NO.
21 & 22	INLET HEADER 6" PIPE SCH XX SA-106C	1-REQ'D
23 & 24	WATER WALL TUBES 1⅝" OD × .220 MW SA-210A	43 REQ'D
25 & 26	WATER WALL TUBES 1⅝" OD × .220 MW SA-210A	32 REQ'D
27 & 28	WW OUTLET HEADERS 6 PIPE SCH XX SA-106C	1-REQ'D
29 & 30	TRANSFER PIPE 2½ OD × .200 MW SA-106	6-REQ'D
31	BUNDLE #1 INLET HEADER 8" PIPE SCH 160 SA-106C	1-REQ'D
32	BUNDLE #1 OUTLET HEADER 6 NOM × 1.28 AW SA 376 TP 304H	2-REQ'D
33A	BUNDLE #1 TUBES 1½ OD × .325 MW SA-210A	120-REQ'D
33B	BUNDLE #1 TUBES 1½ OD × .192 MW SA-213-T2	120-REQ'D
33C	BUNDLE #1 1½ OD × .375 MW SA-213-T11	120-REQ'D
33D	BUNDLE #1 TUBES 1½ OD × .385 MW SA-213-T22	120-REQ'D
33E	BUNDLE #1 TUBES 1½ OD × .282 MW SA-213 TP 304H	120-REQ'D
*	FOR BUNDLES 2 & 3 THE SAME MATERIAL CHANGES ARE REQ'D AS FOR SUPERHEATER #1	
34	BUNDLE SUPPORT HEADER 8⅝" OD × 1½ AW SA 376 TP 304H	2-REQ'D
35	OUTLET PIPE 3½ PIPE .449 WALL SA 376 TP 304H	8-REQ'D
36	BUNDLE #2 INLET HEADER 5 PIPE SCH 160 SA 106 C	1-REQ'D
37	BUNDLE #2 OUTLET HEADER 6 PIPE SCH XX SA 376 TP 304H	2-REQ'D
38	BUNDLE #3 INLET HEADER 4" PIPE SCH 160 SA 106-C	1-REQ'D
39	BUNDLE #3 OUTLET HEADER 6" PIPE SCH XX SA 376 TP 304 H	2-REQ'D

DESIGN NOTES

1. WATER/STEAM PRESSURE PARTES ARE DESIGNED TO SECTION I OF POWER CODE
2. SHELL DESIGNED TO SECTION VIII UG 27 UNFIRED.
3. SHELL 320 PSIG @ 500°F
4. WATER WALLS TEMP 700°F AND PRESS 2700 PSIG
5. SUPERHEATER TEMP 1000°F FST @ 2700 PSIG
6. WATER WALLS 12 PSI DIFFERENTIAL BETWEEN FLUID BED AND SHELL

GENERAL NOTES

1. DO NOT SCALE THIS DRAWING. USE FIGURE DIMENSIONS ONLY.
2. ABBREVIATIONS USED ON THIS DRAWING ARE IN ACCORDANCE WITH AMERICAN STANDARD "ABBREVIATIONS FOR USE ON DRAWINGS."
3. ALL NOZZLES LISTED IN NOZZLE CHART, WW INLET AND OUTLET CONNECTIONS AND SUPERHEATER INLET AND OUTLET CONNECTIONS TO HAVE BELLOWS SEALS AT PENETRATIONS OF VESSEL SHELL.

NOZZLE CHART

NO	I.D.	[illegible]	SERVICE	NO. REQ'D
1		1	COAL/DOLOMITE INJECTION	6
2	8	20	DOLOMITE WITHDRAWAL	1
3		2	DOLOMITE INJECTION	3
4	8	20	FINES RETURN	1
5		4	IGNITION NOZZLE	8
6		1	PDR	3
7		1	PDRC	2
8		1½	TI, TR	7
9		1½	TSH, TAH	1
10		SPECIAL	TI, TR (FLUID)	19
11		SPECIAL	TI, TR (SKIN)	6
12		20	AIR INLET	1
13		1½	TEST LOOP	2
14		1	SAMPLE CONNECTION	3
15	18	30	HEATER H-102 NOZZLE	1
16	18	30	MANWAY	6

LEGEND

TI	TEMPERATURE INDICATOR
TR	TEMPERATURE RECORDER
PDR	PRESS DIFFERENTIAL RECORDER
PDRC	PRESS DIFF RECORDER CONTROLLER
TSH	TEMPERATURE SWITCH HIGH
TAH	TEMPERATURE ALARM HIGH

This Drawing is the Property of the
FOSTER WHEELER CORPORATION
[illegible]

PRESSURIZED FLUIDIZED
BED BOILER
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PENNSYLVANIA

DRAWN BY [illegible] SCALE NONE [illegible] 11-52338 DWG. NO. OP-720-9

Figure 7

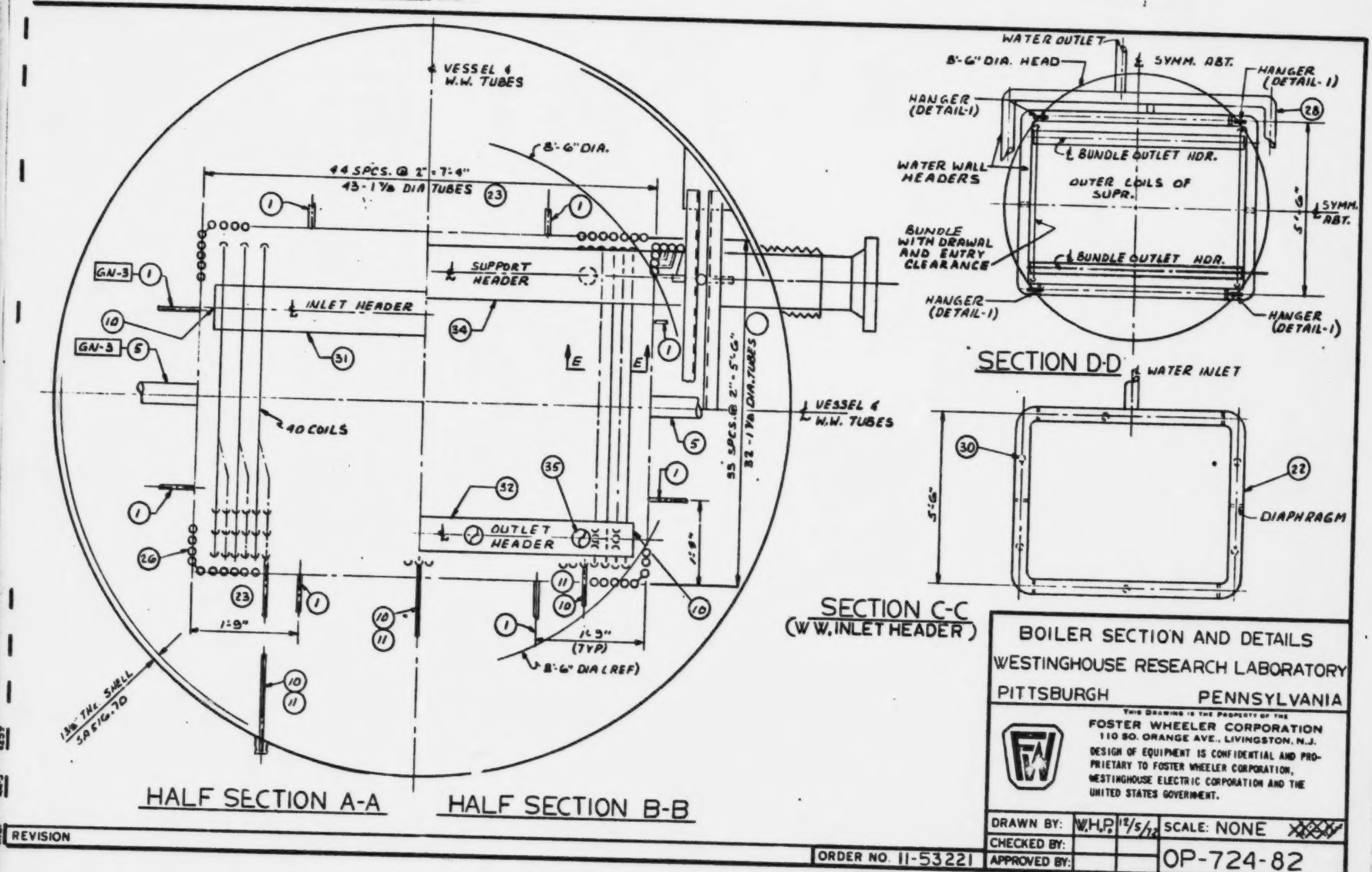


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Figure 8

TABLE 3

MATERIAL BALANCE - NOMINAL DESIGN[a]

Stream No.	Description	Temp. °F	Pressure psia	Flow Rate lb/hr	Composition		Particle Size
1	Wet coal from BL	ambient	15	120,000[b]	moisture	10.0 wt.%	1-1/2" x 0
					VCM	36.8 wt.%	
					fixed carbon	45.3 wt.%	
					ash	7.9	
					Total	100.0	
2	Sized Coal	100	15	111,240[b]	C	71.3 wt.%	1/4" x 0
					H	5.4 wt.%	
					O	9.3 wt.%	
					N	1.3 wt.%	
					S	4.3 wt.%	
					ash	8.5 wt.%	
					Total	100.0	
3	Dolomite	ambient	15	150,000[b]	$CaCO_3$	49.59 wt.%	1/4" x 28 mesh
					$MgCO_3$	49.36 wt.%	
					inerts	1.05 wt.%	
					Total	100.00	
4	Dolomite	ambient	15	35,728	same as Stream 3		1/4" x 28 mesh
5	Coal to R-101	ambient	176.4 min.	22,000	same as Stream 2		1/4" x 0
6	Spent Dolomite	1600	176.4	20,979	$CaSO_4$	18.0 wt.%	1/4" x 0
					CaO	39.3 wt.%	
					MgO	39.6 wt.%	
					inerts	1.8 wt.%	
					ash	1.3 wt.%	
					Total	100.0	
7	Fines Discarded	1600	165	2,900	ash	60.0 wt.%	
					carbon	30.0 wt.%	
					dolomite	10.0 wt.%	
					Total	100.0	
8	Fines Discarded	1600	165	1,432	same as Stream 7		
9	Fines Discarded	1600	165		same as Stream 7		

[a] Nominal design is Case A-1; see Appendix II.

[b] Flow rate based on 40 hr. operation per week.

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TABLE 4

MATERIAL BALANCE - NOMINAL DESIGN[a]

Stream No.	Description	Temp °F	Pressure psia	Flow Rate lb/hr	Flow Rate MMSCFD	Composition	Dust Loading gr/ACF
10	Air to C-101	ambient	14.3	366,504	116.8	O_2 20.6 M % N_2 77.3 M % H_2O 2.1 M % Total 100.0	
11	Air to C-103	100	180	53,500	17.0	O_2 21.0 M % N_2 79.0 M % H_2O nil Total 100.0	
12	Air to R-101	500	175	238,988	76.17	same as Stream 10	
13	Air By-passed	500	175	73,611	23.46	same as Stream 10	
14	Flue Gas from R-101	1600	168	273,737	82.8	CO_2 18.3 M % CO 0.2 M % H_2O 8.5 M % O_2 1.7 M % N_2 71.2 M % SO_2 148 ppm NO 198 ppm	20.8
15	Flue Gas from G-101	1600	165	273,737	82.8	same as Stream 14	~3.01
16	Flue Gas to Turb. Cascade	1600	165	60,000	18.1	same as Stream 14	~0.30
17	Flue Gas to Quench	1600	165	213,737	64.7	same as Stream 14	~0.30
18	Quench Water	200	185	65,683	131 gpm		
19	Flue Gas to SL-101	600	atm	339,420	116.1	CO_2 11.5 M % CO 0.12 M % H_2O 42.9 M % O_2 1.1 M % N_2 44.4 M % SO_2 92 ppm NO 124 ppm	~0.30

---

[a] Nominal design is Case A-1; see Appendix II.

TABLE 5

HEAT BALANCE AROUND FLUIDIZED BED BOILER

Nominal Design[a]

Datum: 77°F

	Lb/Hr	Temp. °F	MM Btu/Hr
Input			
Dried coal	22,000	77	
Sensible heat			0
LHV			275.0
Comb. air	238,988	500	24.98
Fresh dolomite	35,728	77	0
Fines returned	2,900	1600	1.13
TOTAL	299,616		301.11
Output			
Flue gas	273,737	1650	119.4
Spent dolomite	20,979	1650	8.1
Fines elutriated	4,900	1650	1.9
Reaction heats			
Reactions with dolomite			
$CaCO_3 + SO_2 + 1/2\ O_2 = CaSO_4 + CO_2$			-3.91
$CaCO_3 = CaO + CO_2$			11.4
$MgCO_3 = MgO + CO_2$			10.58
No formation			
$1/2\ N_2 + 1/2\ O_2 = NO$			0.07
Incomplete coal combustion			
$CO_2 = C + O_2$			1.69
$CO_2 = CO + 1/2\ O_2$			2.08
Heat loss			0.20
TOTAL	299,616		151.51

Heat Available for Steam Generation = 301.11 - 151.51
= 149.6 MM Btu/Hr

---

[a] Nominal design is Case A-1; see Appendix II.

for convenient tube bundle removal or installation and permits a continuous tube bundle to provide superior fluidized bed hydraulics. A second design was conceived which contains three separate bundles which can be stacked one above the other with three feet of crawl space between the bundles for assembly and maintenance. Headers are located in the preheat air zone where temperatures are low (∿ 600°F). This design requires extensive cutting and welding to change tube bundles and has discontinuities in the tube bundle for deep bed operation. Both designs are presented in the Appendix.

The tube bundles can be operated as either a superheater, an evaporator, or a preheater; or, by reducing the mass flow, as a combined evaporator and superheater.

The use of a refractory backed by structural steel for one or more walls of the boiler has been considered as a means of simplifying construction and of easing maintenance. The water-wall construction, however, seems to have all the advantages:

- Lower cost
- Less bulk
- Cheaper fabrication, less maintenance
- Better means of support for submerged tubes
- More heat exchange surface.

The possibility of locating headers for the tube platens within the water walls has also been considered as a means of easing the removal and/or replacement of tube bundles. More expensive materials and costlier fabrication techniques would be required, but significant savings in carrying out repairs would be realized.

4.5 AUXILIARY EQUIPMENT

4.5.1 Dolomite and Coal Preparation and Feed

Wet coal is received in open-rail cars and in the size range of 1-1/2 in. x 0. The cars are unloaded over a hopper below the tracks.

The hopper feeds a conveyor to a dryer where coal is dried (from as high as 10%) down to ∿ 3% moisture. The coal is crushed to 1/4 in. x 0 and then conveyed to a covered silo for storage. Coal may then be blended with dry, crushed dolomite in the order of 10% of the coal. The coal plus dolomite is pressured up to boiler fluidized bed pressure, and then it is injected into the boiler through a Petrocarb pneumatic injection system.

The dolomite is received dry and double-screened 1/4 in. to 28 mesh in covered rail cars. The cars are unloaded in a closed building into an underground hopper to prevent the picking up of moisture. The dolomite is elevated by conveyor to a storage silo, from where it is either pressurized in a lock hopper and then injected into the boiler or added to the coal for injection into the boiler. The dolomite can be injected above the grid.

Spent sorbent is discharged from the bottom of the bed, a position just above the grid, or it may be withdrawn at 24 in., 48 in., and 72 in. from the bottom of the tube bundle, depending upon the position of the grid with respect to the tube bundle.

4.5.2 Water and Steam Supply

The water and steam are assumed to be available at 2400 psig at the capacity required by the development plant. The water at 500°F and under pressure would be received from the utility power company's economizer and sent to the water walls for preheating and evaporation. Saturated water and saturated steam from the flash drum are returned to the utility company. Either water or saturated steam is taken from the utility company and sent to the fluidized bed tube bundle. The saturated steam is superheated to 1000°F, or the water is evaporated in the tube bundle and returned to the utility company.

4.5.3 Dolomite and Ash Disposal

Solids disposal is accomplished by cooling the ash plus the spent sorbent in a water-jacketed rotary cooler to 300°F from a temperature of 1750°F, with equipment design adequate for 2000°F. The ash is then conveyed to the utility's ash pile for disposal.

4.5.4 Steam Disposal

Normally, all steam is returned to the utility. In the case of an independent site without a nearby utility, the steam from all sources (flash drum, tube bundle, or water jackets) would have to be condensed, and the condensate less the blowdown would be returned to the boiler feedwater storage and pumped into both the developmental boiler and the package boiler.

4.5.5 Particulate Removal

Hot flue gas at 1600 to 1750°F and at 155 psig leaves the boiler together with most of the ash and some dolomite, as well as a small amount of unburned carbon. The larger-sized solids are removed from the hot gases in a single-stage cyclone. Solids may be returned to the combustion zone if the carbon loss is high, but it is believed that the combustion zone is large enough to ensure adequate residence time for complete reaction of the coal. With complete combustion and negligible solid carbon carry-over, the first-stage cyclone dust will be sent to the cooler through lock hoppers. The flue gas will then be sent to a final cleanup consisting of a centrifugal or tornado-type cyclone. Most of the particles 5 μ and larger are removed. If this equipment should prove unsatisfactory for either gas-turbine or pollution control, space is allowed for inclusion of alternative particulate removal equipment such as sand filters or ceramic filters.

4.5.6 Combustion Gas Disposal

Flue gases from the test cascade or from the turboexpander will be quenched to drop the temperature. The pressure will be lowered to atmospheric, and then the gas will be sent to a stack through a silencer. In a commercial unit, extra heat recovery equipment and recuperators would be installed on the turbine exhaust gas to recover the most heat possible from the flue gas in order to maximize the thermal efficiency.

4.6 GAS-TURBINE TEST FACILITY

A test facility consisting of a rotating multistage turbine and two stationary test passages is recommended for the development plant. This test facility, used in conjunction with analytical studies, will allow assessment of turbine blade erosion or deposition due to particulate matter and hot corrosion and/or deposition initiated by alkali metal compounds in the gas stream. The multistage test turbine will provide information on the effects on erosion and deposition of temperature variations through the turbine flow path, radial pressure gradients, local flows due to stage to stage interactions, and particulate carry-over to later stages. One stationary test passage, designed with long particulate acceleration nozzles to obtain the high particle impact velocities that will be typical of an electric utility gas turbine, will be used to correlate test-turbine erosion to full-scale turbine erosion. An additional full-scale first-stage turbine nozzle cascade will assess damage to this highest temperature component. Figure 9 is a schematic of the test facility indicating the two stationary test passages and the rotating test turbine.

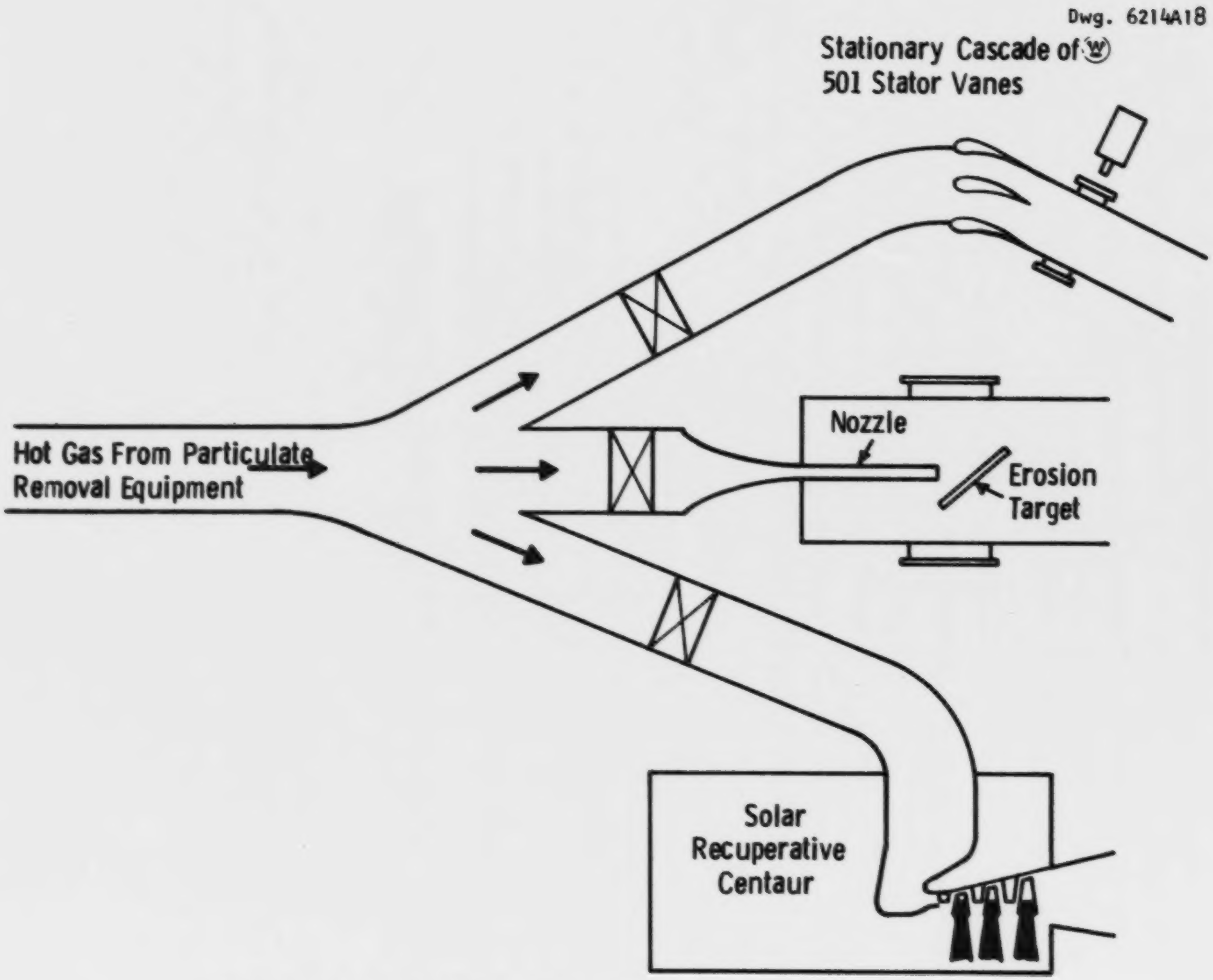

Figure 9: Gas-Turbine Erosion and Corrosion Test Facility

Conditions selected for the development plant turbine must ensure operability of a large electric utility gas turbine. Operating conditions must be duplicated in such a way that the potential for condensation of volatile alkali metal compounds - sodium and potassium chlorides and hydroxides and subsequent reaction to sulfate or molten sulfate-chloride mixtures - can be studied. Provision must be made to measure the rate of deposition of any deposits. This requires similar gas and metal temperatures at points of corresponding pressure, and similarity of flow conditions. Blading must be of hot corrosion resistant materials so "hot corrosion" attack of the test turbine will be comparable to attack of the large turbine. Erosion damage will be comparable if the velocities of particulate impact with turbine components are comparable in both magnitude and impact angle. A number of turbines capable of handling the gas flow available from the development plant were identified (Table 5). Detailed engineering comparisons were made between the turbines shown in Table 6.

4.6.1 Test Turbine

The recuperative version of the Solar Centaur industrial gas turbine appears attractive for the multistage rotating test vehicle. This machine is of the right scale for pilot plant operation. Its gas flow requirement (42 lbs/sec) is less than the bed output (76 lbs/sec) but is sufficiently large to be useful as a demonstration of the viability of the overall concept. The inlet temperature of 1600°F is acceptable for use on the fluidized bed combustion system, and the turbine can accept the required 10 atmosphere inlet pressure.

Corrosion resistance of the first two stages of the Solar turbine is approximately comparable to that of a modern electric utility gas turbine. The third-stage stator nozzles and blades should be replaced with those made of more hot-corrosion resistant materials such as alloys having at least the corrosion resistance of MAR 421.

TABLE 6

SURVEY OF GAS TURBINES FOR DEVELOPMENT PLANT[a,b]

Company	Gas-Turbine Model	PR	Wa	Wa/PR
Cooper Bessemer	Coberra 30	6	38	6.3
De Laval	TP350	9	34	3.8
Detroit Diesel	501 - K	9	31	3.5
General Electric	7LM350	6	44	7.3
General Electric	M1402	5.9	39	6.6
General Electric	M1502	7.0	45	6.4
Ingersoll Rand	JT-35	8.5	31	3.7
I-H Heavy Ind.	T64-1H1-10	12.7	24.5	1.9
Lycoming	T35	8.0	?	?
Mitsui	SB150	6.5	28.7	4.4
Nordberg	G-55-2	7.4	60	8.1
Orenda	OT-C-516	4.1	23.8	5.8
Rolls Royce	Proteus	7.3	43.40	6.0
Ruston	TF1200	6.5	23.8	3.7
Ruston	TB3000	5.85	43.0	7.2
Ruston	TB1500	4.2	23.4	5.5
SNECMA	THS2000	14.5	54	3.7
SOLAR	T3001	8.0	32.2	4.0
Stal-Laval	HP components from GT35	4.0	65.0	16.0
Turbomeca	Marbore II	3.85	17.6	4.6
Turbomeca	Marbore VI	3.72	21.2	5.7
Turbomeca	Larzac	9.0	57.0	6.4
Turbo Power	FT12A	?	?	?
and marine	GG12A	?	?	?
Canadian Ⓦ	W101	6.6	124	18.8

---

[a] Source: Sawyer's Gas Turbine Catalog for 1971

[b] Development plant design conditions: plant capacity - 10 to 30 MW; airflow, Wa - 20 to 65 lb/sec; pressure ratio, PR - 10:1; Wa/PR - 2.0 to 6.5.

TABLE 7

COMPARISON OF TEST TURBINES FOR FLUIDIZED BED COMBUSTION PROCESS DEVELOPMENT PLANT

Turbine	Power Output	Mass Flow	Inlet Temp.	Max. Gas Velocity	Pressure Ratio	Stages	RPM	Power Absorber	Comments
Large Electric Utility	70 MW	760 lb/sec	~2000°F	2200 ft/sec	10:1	4	3600	-	turbine to be simulated
Can. ③41	6300 HP	75 lb/sec	1500°F	1250 ft/sec	6:1	4	8900	generator + load bank or supercharger	inlet temp. seems too low gas velocity seems too low
Lycoming T-55 Aircraft	3000 HP		2000°F +	2100	8:1 [a]	4	16,000 (power stages)	Lycoming water brake	must break through engine housing to duct compressor out and hot gas in-Lycoming dubious about struc. integrity
Lycoming T-55 Gas Producer Stages	up to 8000 HP	up to 30 lb/sec	1800°F uncooled 2000°F + cooled	1600	a	2		Lycoming water brakes (2)	Lycoming recommendation-rig construction involved-blade cooling first row stator and rotor-
Solar Regenerative Centaur	3500 HP	35 lb/sec	1600°F	1400 [b]	8:1	3	15,000	Generator + Load Bank	least modification necessary, compressor outlet and hot gas inlet integral with unit. How dump compressor air?

[a] Turbine housing designed for operation at up to 10 atmospheres (a) inlet pressure.

[b] At 10:1 pressure rate.

The regenerative configuration of the machine provides both compressor outlet and hot gas feed in locations that are immediately accessible.* The recuperative Centaur is virtually identical in all important characteristics to the present production model of the Centaur (except for the compressor outlet and hot gas inlet) and should be reliable.

Gas velocities relative to blading approach those of a large electric utility gas turbine (similar to the Westinghouse 501) at the rotor trailing edges and at the exit to the third-stage stator. At other locations in the turbine, however, the gas velocities are considerably lower, typically reaching only about 50% of the Westinghouse 501 gas velocities at blade and vane leading edges.

If the particle velocities exactly follow the gas velocities, the erosion rate of the Solar blading at the rotor trailing edges and at the exit to the third-stage stator should be comparable to that in the Westinghouse 501, while the erosion rates at the leading edges of stator vanes and rotor blades may be as low as 6% of those at comparable locations in the full-size machine. Because of the rapid acceleration of the gas passing through the stator vanes and the deacceleration in the rotor blading, particles as small as 2 μ in diameter may have too much inertia to follow the gas flow. An analysis of this effect in a full-scale electric utility turbine showed that the variations in particle velocities lagged the variations in gas velocity. This effect increased with increasing particle size and resulted in particulate velocities leaving the rotors that were significantly higher than the gas velocity. A similar analysis of the test turbine flow path must be made to allow the erosion data to be interpreted properly.

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*Note: In designing this facility, the turbine inlet design must be carefully examined to control dust concentrations presented to the first-stage vanes.

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4.6.2 Stationary Test Passages

The fact that impact velocities cannot be duplicated in the rotating test facility is the reason that the stationary passage erosion tests mentioned earlier are required. Particle acceleration nozzles of sufficient length ($\approx$ 4 ft with nozzles whose flow areas decrease linearly with length) must be used to provide sufficient time for particles to reach gas velocity before impacting the erosion targets. Erosion targets must be carefully designed so that the impact angle as well as the velocity is accurately known at the locations where erosion rates are measured.

First-stage stationary vane erosion/deposition can be measured in a stationary cascade provided that full-scale vanes are used in the passage. Such a cascade would require about 16 lbs of gas for each nozzle passage used in the cascade. The effect of cooling airflows on deposition and erosion could be effectively studied in this facility.

4.6.3 Test Rig -- Required Engineering

The recuperated Solar Centaur turbine has a three-stage turbine of which the first two stages are used to drive the axial compressor. The compressor cannot be divorced from the turbine, and the engine must be bought as a unit which would be mounted on a bed plate including its own lubrication and necessary control system. The manifolding for the inlet and outlet to and from both the compressor and the turbine would be part of the package, but Solar would not wish to undertake the design of the hot gas ducting to the turbine. They would give advice in the load transference system to the turbine manifolding. The load absorption system for the power turbine, which could be either generator or water brake, could also be supplied by Solar with the mounting bed plate. It would, therefore, be necessary to engineer and supply for this engine the following:

- The hot gas ducting to the turbine
- The ducting from the axial compressor including the control valve gear to allow it to be operated at correct conditions
- The cooling arrangements for the load absorption
- A control link-up between the hot gas flow control and turbine speed to provide overspeed protection.

Table 8 estimates the cost of the rotating test rig. (The costs of reblading third-stage rotors and stators have not been included.)

TABLE 8

APPROXIMATE COST OF ROTATING TEST RIG
BASED ON SOLAR RECUPERATIVE CENTAUR ENGINE
(Solar-Westinghouse Estimate)

Basic Cost of Solar Regenerative Gas Turbine including Generator or Water Brake, Bed Plates, Manifolding, Lubrication and Controls	$300,000
Inlet and Exhaust Ducting for Axial Compressor and Control Valves	15,000
Exhaust Ducting for Turbine Expansion Joint, etc.	30,000
Turbine Inlet Ducting. Design and Manufacture including Control Valves	75,000
Cooling System for Load Absorber	50,000
TOTAL	$470,000

Table 9 estimates the cost of the two test passages.

TABLE 9

COST OF TWO TEST PASSAGES

Design	$ 60,000
Manufacture of Two Test Passages including Control Valves	200,000
TOTAL	$260,000
Estimated Total Test Facility Cost.	$730,000

4.7 REGENERATION/SULFUR RECOVERY

Unlike the boiler where a design concept is established, sufficient data are not available to permit the selection of a preferred regeneration process (see Volume I). A process might be selected for the development plant on the basis of available data, but the available data are inadequate to design equipment. Several key parameters which determine the equipment sizing cannot be specified. Areas of uncertainty include:

- Sulfur in the spent stone and stone circulation rate from the boiler
- Regenerator operating conditions which determine the quantity of heat which must be supplied to or removed from the process
- SO_2 or H_2S concentration which is related to gas supply requirements to the regenerator and the sulfur recovery equipment.

An evaluation was made to determine if a regeneration system could be designed with sufficient flexibility to study alternative processes. Such flexibility cannot be provided economically at this time. Since sufficient information is not available, the plant is designed for once-through operation, and a regeneration system is not included in the preliminary design. Provisions are made for a regeneration system -- space, stone feed to the boiler, and removal -- which can be installed at a later date.

4.8 INSTRUMENTATION AND CONTROL

Instrumentation and control for a commercial plant are discussed in Volume I, Section 5. The development plant will provide the opportunity to test and demonstrate the proposed operating procedure and controls.

Control of the boiler differs slightly from the standard once-through boiler practice but is very similar to the process industry's practice. In a conventional boiler, variation in the steam side operation affects the radiant combustion zone only very slightly. In a fluidized bed unit, however, a slight variation in steam flow rate, temperature,or heat transfer immediately affects the fluidized bed temperature.

For the development boiler, the steam pressure is controlled at 2400 psig, which is in line with modern power plant practice for subcritical installations. The superheat outlet temperature is limited to 1000°F; this temperature readjusts the water-flow control rate to the tubes in the fluidized bed. The fluidized bed is maintained at the proper pressure by back-pressure control on the effluent gas or on a by-pass around the turboexpander. The temperature in the fluidized bed is used to readjust the coal feed rate, automatically, after which the air rate is manually adjusted to provide the excess combustion air at the desired percentage of the flue gas.

The reason for manual readjustment of the air rate is that a very slow response is desired so as not to destroy the fluidized bed characteristics of the boiler. Too rapid a response in air rate may either entrain the entire bed or cause the fluidized bed to collapse.

The emergency control systems will involve immediate stopping of the flow of coal to the boiler. This will occur under such conditions as:

- Power loss or failure
- Instrument air loss
- Low pressure in fluidized bed
- High pressure in fluidized bed
- Low-pressure combustion air
- Low-pressure injection air.

If the coal flow is halted by an emergency condition, the airflow will continue for five minutes and then slowly by-pass the boiler. The air compressors will then be stopped automatically.

The demonstration of satisfactory operation of a fluidized bed boiler depends upon both the efficient generation of steam as well as upon the reduction of pollutants such as SO_2, NO_2,and particulates.

To reasonably demonstrate satisfactory pollution control, the effluent flue gas will be monitored for particulates, SO_2, and NO_x, as well as for the usual effluents of CO_2, O_2, and CO.

Particulates can be monitored by means of a beta gage attenuation of particles deposited on a moving tape (Freeman Laboratories) or by means of particles deposited on the surface of piezoelectric quartz crystals (Thermal Systems, Inc.). These methods allow a calculated value of particulate concentration in weight of solids per unit volume of gas flow; but it is also necessary to determine particle size distribution for proper operation of cyclones and dust removal equipment, and for extended operation of the turboexpander. The size distribution can be determined intermittently by means of a multijet impactor (Monsanto Enviro-Chem Systems, Inc.) or by a stack gas sampler (Anderson 2000).

Flue gas components such as SO_2, NO_2, CO_2, SO_3 can be analyzed by infrared and/or ultraviolet methods, oxygen by paramagnetic methods, and NO_x by Chemiluminescence.

4.9 PERSPECTIVE VIEW

A preliminary arrangement of the development plant equipment is shown in the perspective drawing shown in Figure 10. The fluidized bed boiler is contained within the vertical cylindrical vessel in the foreground; behind it and to the right is the coal drying and sizing equipment. Coal and dolomite storage silos and feed systems are shown behind and to the left of the boiler. A compressor shelter in the right foreground has been provided for the air supply system.

The entire installation is contained within a 185 ft x 200 ft site. The top of the pressurized fluidized bed boiler is about 95 feet above grade, and the highest point of the particulate removal system is about 115 feet above grade.

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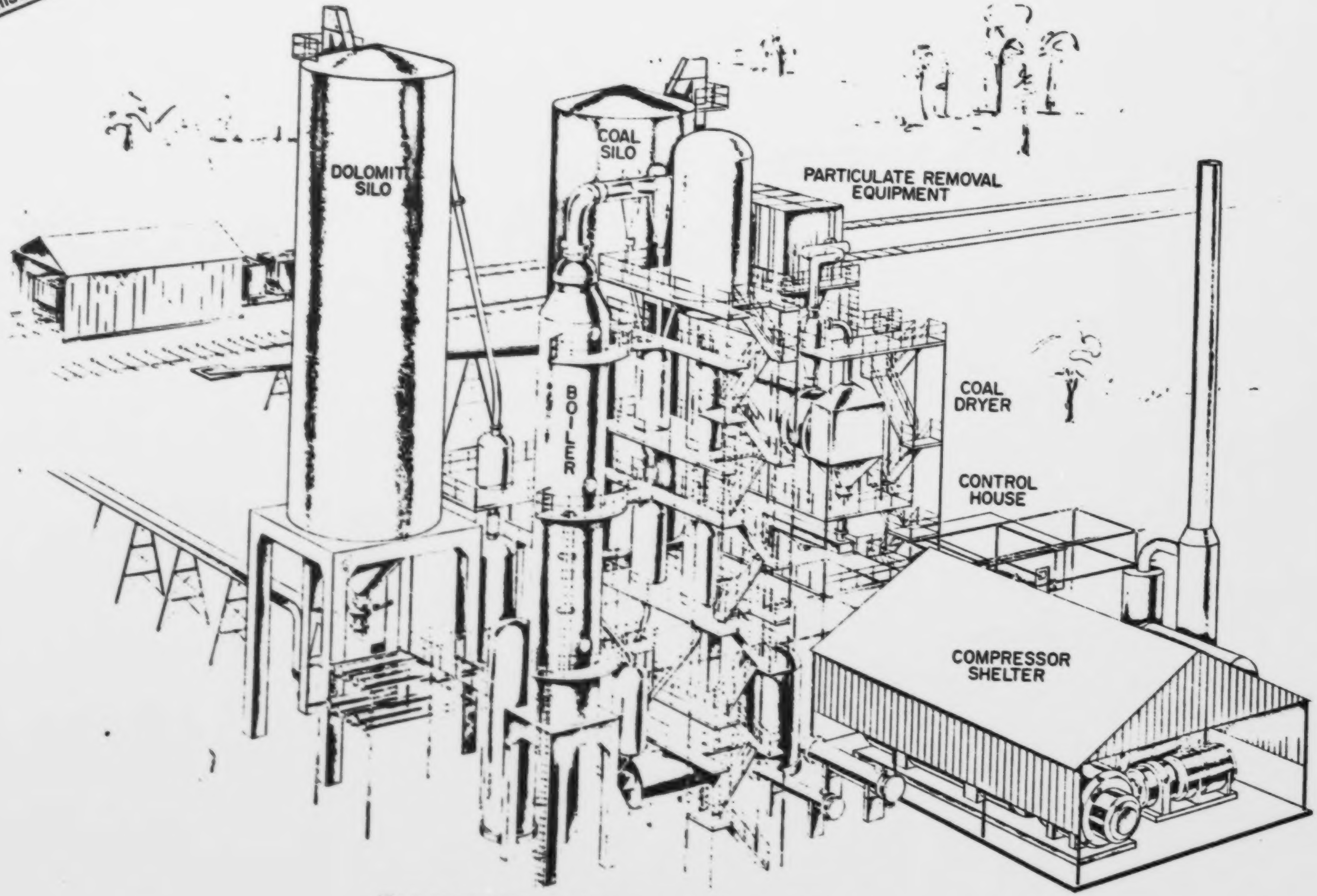

PRESSURIZED FLUIDIZED BOILER PLANT

Figure 10

The structure has been designed to provide ease of access to the boiler and its accessory equipment for maintenance and for normal operating checks. Also, gravity flow of solids into the solids feeding vessels from elevated surge bins is utilized to provide for maximum solids flow reliability.

4.10 PLANT MODEL

A 3/16-in. scale model of the pressurized boiler development plant and a 3/8-in. scale cutaway of the boiler were constructed. Photos of the model are shown in Figures 11 and 12. These models will be used to illustrate the boiler concept and to provide a tool for explaining the development plant concept, selecting a site, and assembling a project team.

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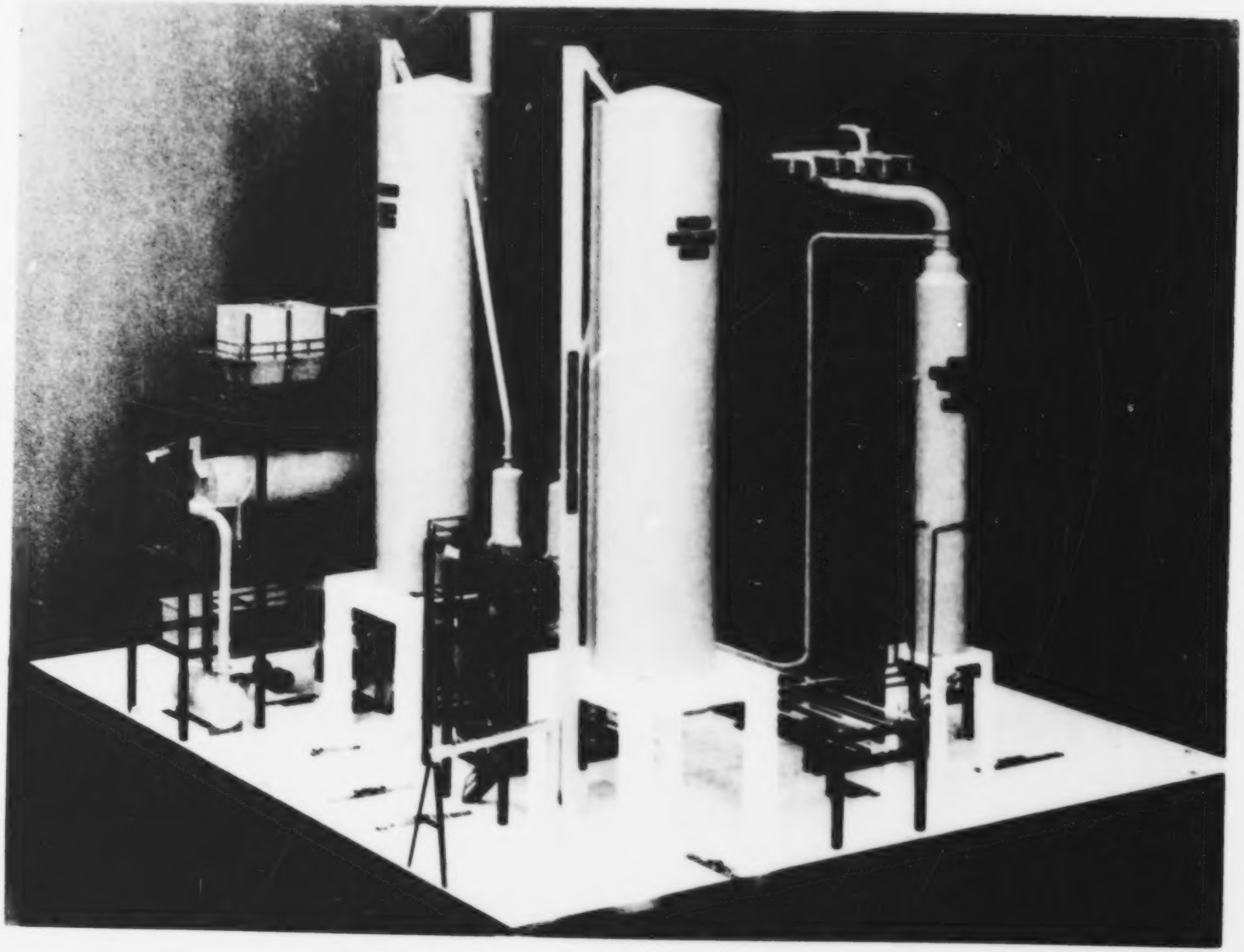

Figure 11: 30 MW Pressurized Fluid Bed Boiler Demonstration Facility

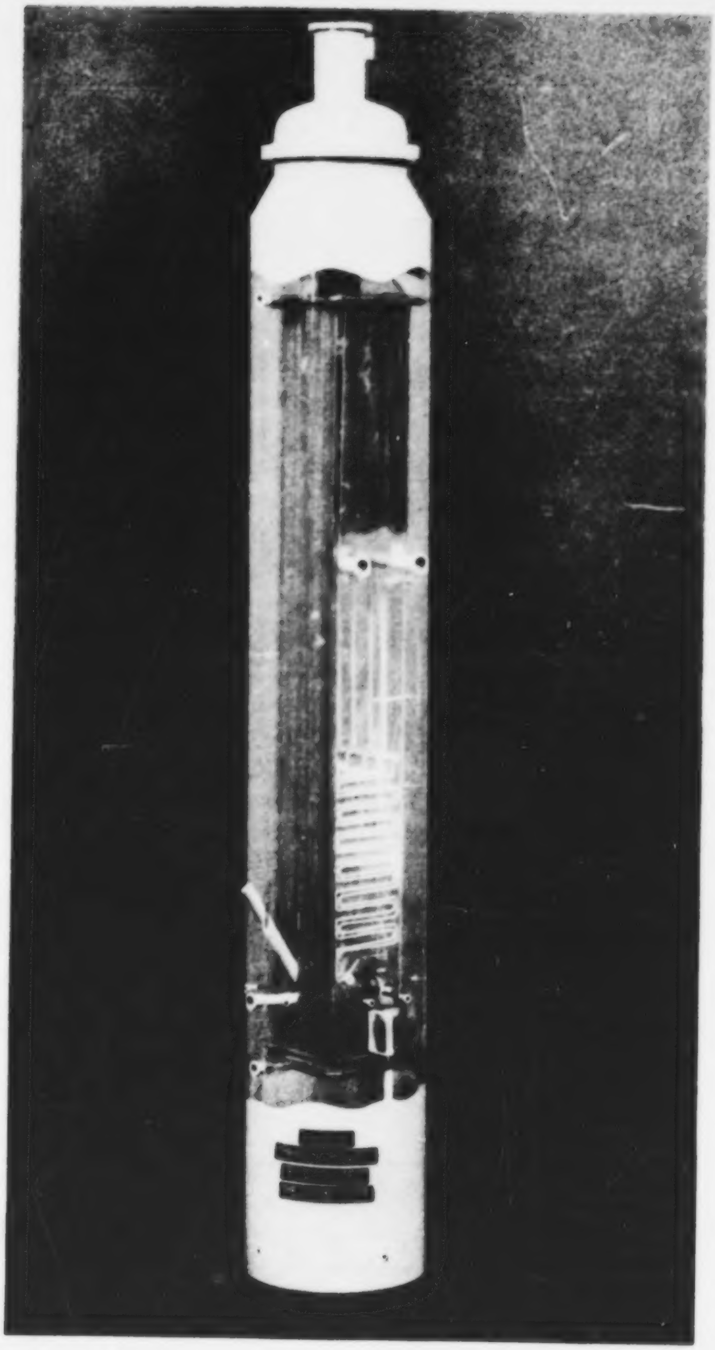

Figure 12: 30 MW Pressurized Fluid Bed Boiler Cutaway

5. EXPERIMENTAL PROGRAM

The experimental program for the pressurized fluidized bed boiler development plant has three objectives:

- To verify that the technical findings made with smaller scale equipment (such as those relating to combustion, pollution abatement, heat transfer, materials, etc.) apply directly or can readily be extrapolated to large-scale equipment
- To study technical problems that can only be studied on larger scale equipment (such as those relating to coal and lime feeding, nonuniform temperature distributions, erosion-corrosion-deposition on moving blades of turbines, etc.); and to demonstrate that no new technical problems (such as vibration and fatigue of boiler tube bundles, etc.) are encountered
- To explore advanced fluidized bed boiler concepts (such as steam generation conditions of 4500 psi/1200°F/1200°F with gas-turbine inlet temperatures of 1900 to 2200°F, recirculating bed boilers, etc.).

The end goal is to provide the technical and economic information, and to create the confidence necessary for proceeding with the installation of a demonstration pressurized fluidized bed combustion power plant.

In order to meet these objectives and to reach the goal, measurements are required over a variety of operation conditions -- inlet and outlet flows, compositions, and temperatures -- sufficient to carry out complete material and heat balances. Such balances permit the computation of combustion efficiencies and heat transfer rates. Analyses of the combustion gas stream emerging from the boiler are required for:

- Primary gaseous components -- O_2, CO_2, H_2O, CO, H_2, N_2, and unburned hydrocarbons

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- Pollutant gases -- SO_2 and NO_x
- Particulates -- ash, attrited sorbent, unburned carbon (both composition and particle size distribution)
- Trace contaminants.

Some gas composition profiles across the bed and through the bed and disengaging zone are desirable. Occasional measurements of the composition and particle size of solids at various points in the bed are helpful in analyzing boiler operation. Measurements of boiler tube vibration and fatigue and of tube and turbine blade erosion and corrosion are required to estimate long-term durability of boiler and turbine. Operating conditions at which measurements should be obtained include primarily the pressure, temperature, airflow, fuel/air ratio, sorbent/sulfur ratio, and bed height over ranges anticipated in the operation of a commercial plant.

To convince utilities that the concept of pressurized fluidized bed boiler operation is practical as well as economical, the boiler must produce steam reliably, must be capable of easy turndown to 50% of its capacity, and must produce combustion gases sufficiently clean to meet pollution control regulations and to provide reliable, long-term turbine blade life.

In order to be convincing, the experimental program must produce data on:

- Boiler dynamic operation characteristics
- Durability of materials and construction in the boiler and turbine
- The ability to provide any maintenance necessary to achieve
  - Uniform and efficient heat transfer
  - Particulate removal from combustion gases
  - Solids feeding to and from a pressurized system.

To meet the requirements just outlined, the experimental program must demonstrate continuous, controllable coal and dolomite feeding in a sufficient number of feed lines to give uniform bed operation for at least 60 days without interruption.

Concurrent with the boiler proof run, data on NO_x and SO_2 emission, and on particulate content at the turboexpander inlet, will be acquired.

Following a 60-day proof run, the boiler system will be subject to a series of tests to experiment deliberately with the start-up, shutdown, and emergency shutdown systems, controls, and operating techniques, in order to determine the best methods for coping with and controlling transient phenomena.

The foregoing experimental program will permit the design and construction of a full-scale power-producing combined cycle pressurized fluidized bed boiler.

The operation of the fluidized bed combustion boiler development plant will be carried out in three phases outlined in Table 10. In the first phase of the experimental program, operating procedures will be proved out; engineering design and performance data will then be gathered on a variety of coals and limestone or dolomite sorbents. In the second phase, overall systems -- boiler, gas-turbine, and regenerator -- control and operation will be investigated; and the long-term (60-day) boiler run will be carried out. Finally, in the third phase of the program, modifications will be made in the boiler to enable the study of advanced boiler designs and operating conditions. Tests will then be carried out to evaluate the effectiveness of such modifications.

TABLE 10

OPERATION OF THE PRESSURIZED FLUIDIZED BED COMBUSTION BOILER DEVELOPMENT PLANT

Phase I Boiler Operating Characteristics
(boiler, test passage, no regeneration)

- Ambient T&P operation
    - Check out solids feeding and withdrawal
      Fluidization
      Particle carry-over
      Water circuitry/boiler tube configuration
    - Use dolomite only
- Ambient T, high P
    - Check out solids feeding and withdrawal
      Fluidization
      Particle carry-over
      Water circuitry/boiler tube configuration
    - Use dolomite only
- Start-up Procedure
    - Check out using start-up burner and dolomite
      w/o coal: ability to reach 700-800°F
      water circuitry
      air control
- Operate with low-sulfur, non-caking coal
- Operate with low-sulfur, caking coal
- Operate with high-sulfur, caking coal

Phase II Long-Term (60 day) System Operation

- Boiler control capabilities
  turndown, operating ranges
- Boiler/gas-turbine expander operation
- Operate with boiler/gas-turbine expander/regeneration

Phase III Concept Alternatives

- Advanced steam conditions
- Boiler tube configuration alternatives
- Higher gas-turbine temperature
- Possible expansion of plant to a four-bed stacked module
- Recirculating bed concept

6. COST ESTIMATE

Factored estimates were prepared for plant capacities from 22,000 lb coal/hr to 33,000 lb coal/hr and operating pressures from 170 psig to 320 psig. Plant costs were prepared for a 'stand alone' plant -- not adjacent to a power plant -- and a development plant adjacent to an existing power plant. A summary of the capital cost estimates, factored from quoted equipment costs, is presented in Table11. Plant cost for the nominal 22,000 lb coal/hr plant at 170 psig is ∿ $10 million erected excluding the gas-turbine test facility. The cost of the boiler unit and extra bundles is ∿ $940,000 -- excluding erection. The main air compressor for the 170 psig plant represents the other major equipment cost: $940,000 excluding erection. The proposed gas-turbine test facility will add ∿ $600,000 to the plant cost. The operating cost for the plant is estimated to range between $2.4 and 3 million per year.

TABLE 11

CAPITAL COST

Coal Capacity lb/hr	Boiler Pressure psig	Site	Plant Cost Delivered & Erected (Factored Estimates)
22,000	170	adjacent to power plant	$ 9,730,000
33,000	320	adjacent to power plant	16,420,000
33,000	320	independent site	19,170,000

7. IMPLEMENTATION

The schedule presented in Figure 13 indicates the basic steps toward a commercial fluidized bed combustion boiler power system which will:

- Reduce capital cost
- Increase operating efficiency
- Reduce pollutant emissions

for electrical energy generation from fossil fuels. Preliminary plans; a detailed design, procurement, and construction schedule; and an overall plant cost estimate have been completed. These plans, schedules, and estimates will be used to locate a plant site, to develop financial backing, and to form a team to construct, operate, evaluate, and lead in the development plant effort. This team should include EPA (and perhaps also other governmental agencies concerned with fuel utilization and power generation), the electric utility industry, electrical generation equipment manufacturer(s), and steam generation equipment supplier(s). Detail design and construction of the development plant could begin in 1974. Information from various laboratory, bench, and pilot operations throughout 1973 and 1974 will be factored in the plant design. Operation of the development plant could begin in 1976. Sufficient information will be available from the development plant to begin design of a demonstration fluidized bed combustion boiler power plant in 1977. This plant could be operational late in 1980.

The program represented by the development plant design and the projected schedule may be altered to adapt to the project team and site selected. Several demonstration program options are available. Five alternatives have been developed for demonstrating the pressurized boiler concept which account for variations in potential plant sites. Table 12 presents projected boiler designs, plant output, and plant costs for the five options. Demonstration of the total power plant concept can also be achieved by a number of different system configurations. Six alternatives have been developed and are presented in Table 13. Possible

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Figure 13

PRESSURIZED FLUID BED BOILER COMBINED GAS-AND STEAM-TURBINE POWER PLANT

ILLUSTRATIVE DEMONSTRATION PLANT PROGRAM

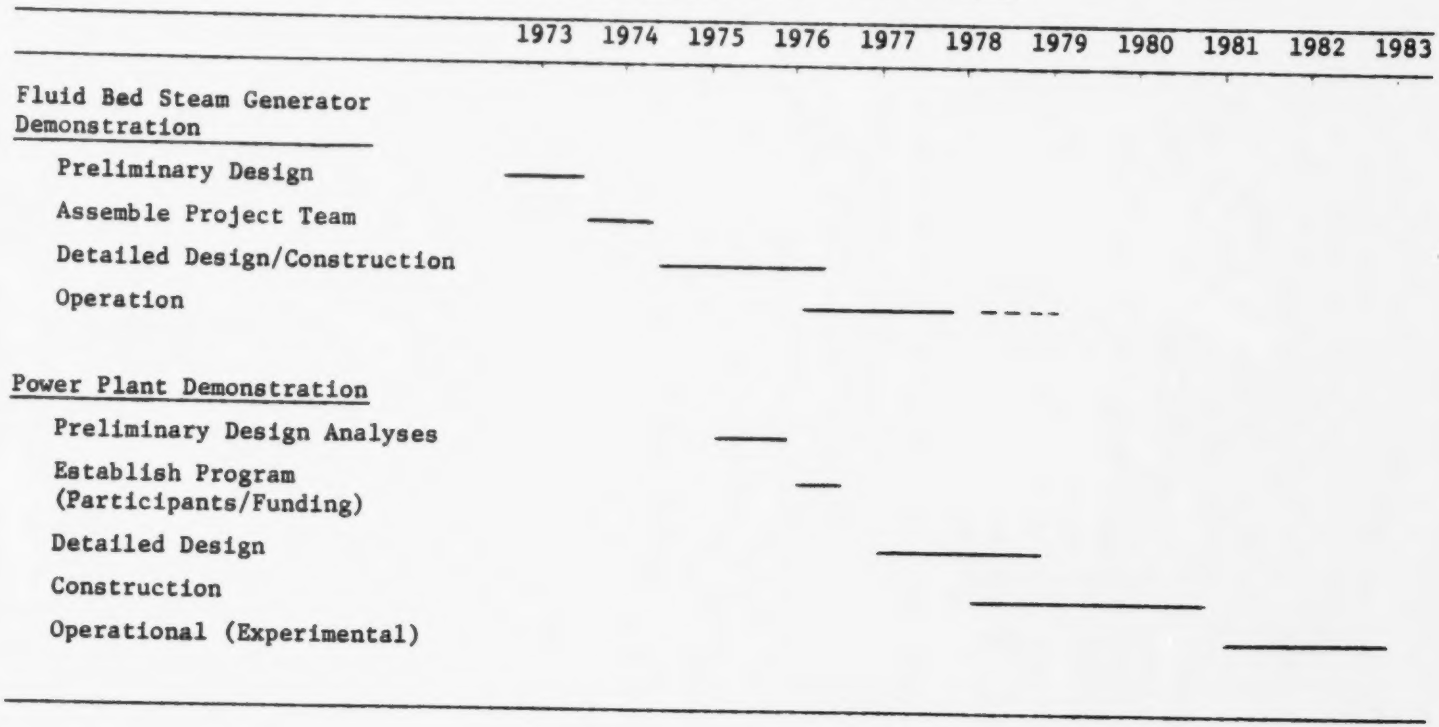

TABLE 12

DEMONSTRATION OF BOILER CONCEPT

	Vessel (dia/ft)	No. of Beds	Coal Input lb/hr	Output	Cost	
					Capital (installed equip)	Operating ($/yr)
1. Stand-Alone Independent Air Supply Independent Water Supply Steam Directly to Condenser	12	1	22,000	180×10^6 Btu/hr (rejected to condenser)	\$$12.5 \times 10^6$	2.5×10^6
2. Process Steam Gas Generator Gas Turbine Steam to Process Condensate Return	12	1	22,000	185×10^3 lb/hr[a] (process steam)	\$$11.9 \times 10^6$	1.7×10^6
3. Gas Turbine Power Gas Turbine with Generator Independent Water Supply Steam Directly to Condenser	12	1	22,000	3.0 MW (G.T. Power) 180×10^6 Btu/hr (rejected to condenser)	\$$12.8 \times 10^6$	1.8×10^6
	12	2	44,000	6.0 MW (G.T. Power) 360×10^6 Btu/hr (rejected to condenser)	\$$18.1 \times 10^6$	2.7×10^6
4. Gas-Turbine Pwr. & Process Steam Gas-Turbine with Generator Steam to Process Condensate Return	12	1	22,000	3.0 MW (G.T. Power) 185×10^3 lb/hr[a] (process steam)	\$$12.2 \times 10^6$	1.7×10^6
	12	2	44,000	6.0 MW (G.T. Power) 370×10^3 lb/hr[a] (process steam)	\$$17.3 \times 10^6$	2.7×10^6
5. Steam Plant Integration Gas-Turbine with Generator Water from Steam Plant Steam to Existing Turbine	12	1	22,000	3.0 MW (G.T. Power) 27 MW (S.T. Power)[b]	\$$10.0 \times 10^6$	1.7×10^6
	12	2	44,000	6.0 MW (G.T. Power) 54 MW (S.T. Power)[b]	\$$14.1 \times 10^6$	2.6×10^6

[a] Based on process steam conditions of 300 psig and 500°F.

[b] Based on 2400 psia, 1000°, 1000° steam conditions.

TABLE 13

DEMONSTRATION OF PLANT CONCEPT

	Module (dia-ft)	G.T. Model	Output MW	Cost	
				Capital[a]	Operating
1. Single Boiler Module	12	English Elect. EA1	~ 75	$\$43.8 \times 10^6$	$\$4.1 \times 10^6$/yr
2. Single Boiler Module	17	W251	~150	$\$69.8 \times 10^6$	$\$6.6 \times 10^6$/yr
3. Two Boiler Module	12	W251	~150	$\$69.8 \times 10^6$	$\$6.6 \times 10^6$/yr
4. Two Boiler Modules (back-fitted into existing steam plant)	12	W251	~ 25 additional	$\$34.9 \times 10^6$	$\$3.4 \times 10^6$/yr
5. Single Boiler Module	12 (1 bed)	Canadian Ⓦ W41 (Mod.)	30	$\$26.2 \times 10^6$	$\$2.2 \times 10^6$/yr
6. Single Boiler Module Steam Generator for Eugene, Ore. Installation	12	English Elect. EA1	13 MW (G.T.) 422,000 lb/hr of steam at 1450 psia-950°F	$\$19.3 \times 10^{6b}$	---

[a] Total plant costs

[b] Installed equipment cost only

boiler designs, gas turbines, and plant costs are indicated in the table. Selection of a particular system will depend on the project team, available site, and economics. An understanding of these and other options will be used to develop a firm demonstration program.

The benefits of a pressurized fluid bed boiler power plant in the economical generation of electrical energy from fossil fuels with minimal pollutant emissions amply justify vigorous pursuit of the recommended program.

8. REFERENCES

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I. Abstract

A coal fed developmental pressurized fluidized bed boiler to generate steam and control SO_2, NO_x and particulates has been designed. Alternates investigated include construction adjacent to a power plant vs. an independent site, coal feed rate at 22,000 lbs/hr (equivalent to 30 MW) vs. coal fed at 33,000 lbs/hr and combustion side pressure of 170 psig vs. 320 psig.

Flexibility has been designed into a single fluidized bed boiler to generate steam in one of three different sized tube bundles, two different fluidized bed grid plates, two different piping arrangements for water-wall tubes, superficial fluidized bed velocities of 6 to 15 ft. per second and bed heights of 10 to 30 feet. Steam is generated at 2400 psig and 1000°F., with the boiler capable of operating in preheat, evaporation or superheat mode or all modes in series.

Capital investment for the case of coal feed rate of 22,000 lbs/hr. at 170 psig boiler casing pressure is $9,730,000 with the total program cost for 3 years of operation including capital investment is $17,024,000. Other alternates increase both capital and operating expense.

II. Description of Plant

1. Description of Flow

The flow through the plant is shown in Figure II, Process Flow Diagram OP-721-433 and on Engineering Flow Diagrams OP-721-423, 424, and 426.

The developmental boiler plant includes coal receiving, crushing, drying and storage. Both coal and dolomite receiving and storage. Both coal and dolomite are injected into the fluidized bed boiler using a "Petrocarb"-type injection system. Combustion air from a centrifugal compressor passes down the annulus of the boiler between the water wall and boiler shell, then passes up through the grid to the fluidized bed. Steam is generated in the water wall tubes and in the tube bundle of the boiler. Flue gas passes through two stages of cyclones to remove particulate matter. Part of the flue gas flow is diverted to a turbine cascade to test turbine blades and the remainder is vented to the stack. A portion of the flue gas can also be diverted to a future turbine expander. Both ash entrained in the flue gas and removed by the cyclones and spent dolomite are depressured, cooled and sent to disposal.

Wet coal from railroad hopper car will be discharged to the below-grade Wet Coal Hopper, CR-101. The coal is then conveyed to the Coal Dryer, RK-101, where the moisture content of the coal is reduced from 10.0 wt% to 3.3 wt%. The dried coal is then discharged to a Vibrating Grizzly where all oversized coal is fed to a Coal Crusher, SR-101. The coal crusher will normally yield coal particle size of ¼"x0. Preheated air from Air Heater, H-101, is used for drying the coal. The elutriated coal dust from the coal dryer is first recovered in the Primary Cyclone, G-103, and finally in a Bag Filter, F-102. The recovered particulate matter is combined with the crushed coal. The coal is then forwarded by a Redler-type Dry Coal Conveyor, CR-102, to the Coal Elevator, CR-103. The coal handling and processing facility in this

II. Description of Plant (continued)

1. Description of Flow (continued)

section is designed for 60 short tons per hour, based on a 40-hour week.

The Coal Silo, D-102, is designed to hold two-days inventory. The silo utilizes a "live shelf" bin section for supplying of coal to the Lock Hopper, D-105. The lock hopper will replenish the Petrocarb's Injection Drum, D-106. Four (4) coal pneumatic conveying lines are provided from the injection drum. The feed rate of coal will be carefully controlled to maintain proper boiler bed temperature.

To replenish the "live shelf", coal is withdrawn continuously from the coal silo and conveyed to the "live shelf" via the coal elevator.

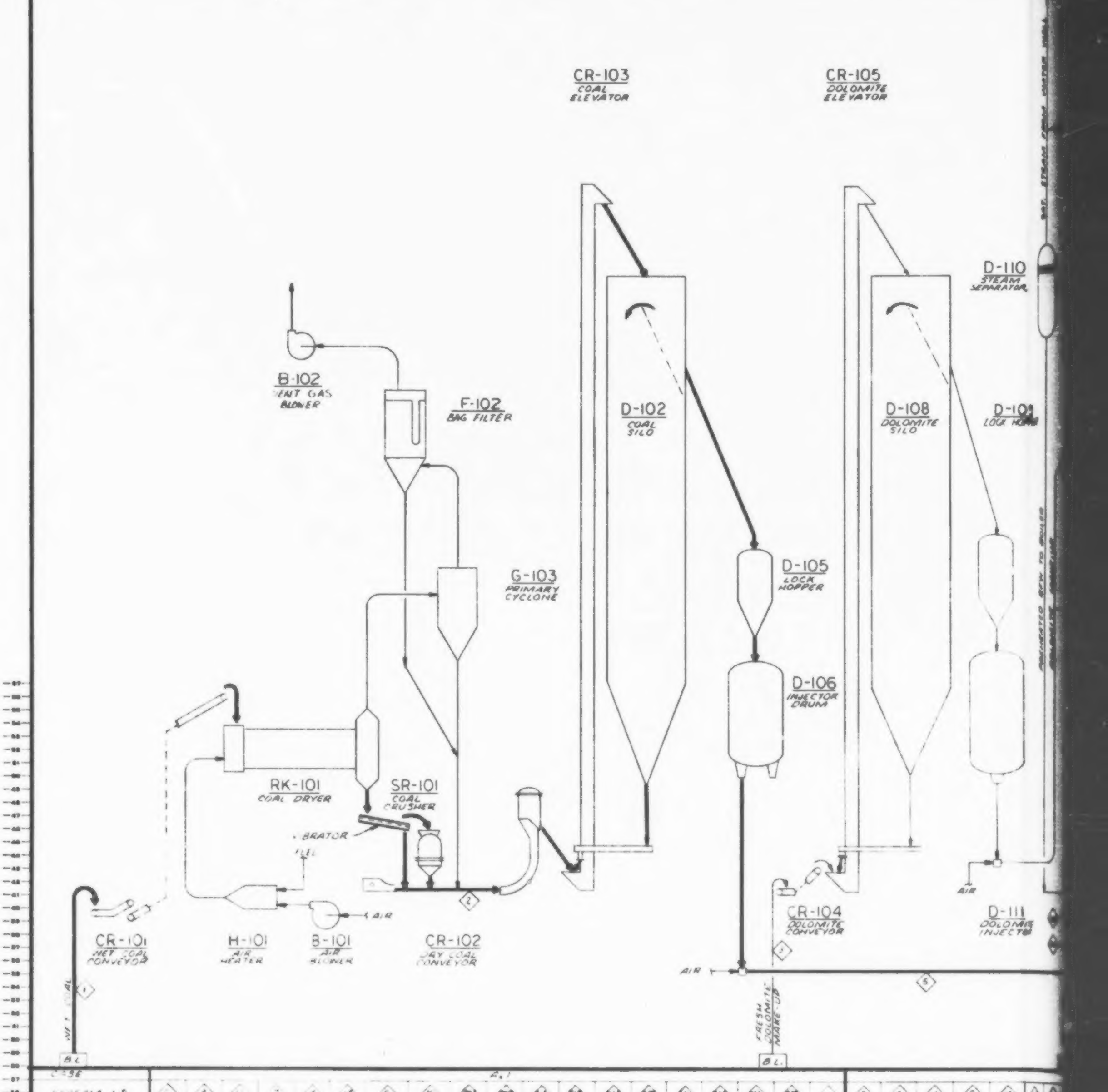
The fresh dolomite for the unit will be purchased as dried and screened to ¼" x 28 mesh. The dolomite will be conveyed from the covered railroad car by Dolomite Conveyor, CR-104, and Dolomite Elevator, CR-105, to the Dolomite Silo, D-108. The dolomite silo is designed to hold two days of inventory. This silo also employs a "live shelf" bin whereby the dolomite is first fed to the Lock Hopper, D-109, under atmospheric pressure. Periodically, the lock hopper is pressurized and feeds the Dolomite Injector, D-111, to replenish its supply. The dolomite is fed continuously to the boiler from the dolomite injector under a controlled rate.

Combustion air required for the fluid bed boiler is provided by the Main Air Compressors, C-101. Compressor, C-101, is designed for 185 psia discharge pressure. In addition to the combustion air requirement, Compressors, C-101, will also provide:

a. Injection and pressurizing air for the Petrocarb's Bulk Material Handling System. This air is obtained from C-103 which takes suction from C-101.

b. Instrument purge and blowback air which is also obtained from C-103,

A



CASE A.1

STREAM Nº		1	4	12	7	9	14	6	16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
COMPONENT	STREAM	COAL	FRESH DOLOMITE	MAIN AIR	FINES RETURN	FLUE GAS	FINES [illegible]	SPENT DOLOMITE	TO TURB CASCADE	BFW TO WALLS	BFW FROM WALLS	BFW TO WALLS	STM FROM D-110	BFW TO BOILER	STM FROM BOILER	STM TO BOILER	STM FROM BOILER	BFW TO BOILER	BFW FROM BOILER	
COAL	LB/HR	21,274																		
$CaCO_3$	LB/HR		17,718																	
$CaSO_4$	LB/HR							3,780												
CaO	LB/HR							8,241												
$MgCO_3$	LB/HR		7,635																	
MgO	LB/HR							8,318												
INERTS	LB/HR		375					170												
CO_2	LB/HR					72,736			14,632											
CO	LB/HR					877			[illegible]											
H_2O	LB/HR	[illegible]	[illegible]	3,155		3,647			3135	250,000	250,000	13,300	13,300	260,000	260,000	255,000	255,000	250,000	250,000	
SO_2	LB/HR					[illegible]			13											
NO	LB/HR					14			2											
O_2	LB/HR	[illegible]	5291	55,069		5,006			297											
N_2	LB/HR	3422	17371	[illegible]		[illegible]031			33,480											
ASH	LB/HR				1,740		334	270												
CARBON	LB/HR				[illegible]		390													
DOLOMITE	LB/HR				290		570													
TOTAL - LBS/HR		[illegible]	38465	238,388	2,300	273,137	4,200	[illegible]	50,000											
TEMP. - °F		AMBIENT	AMBIENT	5[illegible]	1600	1650	1650	1650	1600	212	418	643	663	663	663	275	1000	212	[illegible]	
PRESSURE - PSIA				76.4		170	170		165	2503	2415	2455	2415	2490	2415	2540	2415	2455	2415	
DENSITY LBS/CF				0.482		0.227			0.225											
MOL WT [illegible]		28.8	28.8	28.6		30.2			30.2											
MOL/HR [illegible]		473.7	789.5	8351.9		9075.6			366.8											
MMSCFD [illegible]		4.32	7.20	76.19		82.77			18.12											
SP. GR (LIQ.)																				
GPM (HOT)																				

STREAM Nº		5	4	12	7	14
COMPONENT	STREAM	COAL	FRESH DOLOMITE	MAIN AIR	FINES RETURN	FLUE GAS
COAL	LB/HR	12,764				
$CaCO_3$	LB/HR		10,631			
$CaSO_4$	LB/HR					
CaO	LB/HR					
$MgCO_3$	LB/HR		3,581			
MgO	LB/HR					
INERTS	LB/HR		225			
CO_2	LB/HR					63,942
CO	LB/HR					286
H_2O	LB/HR	48	75	2,765		8,480
SO_2	LB/HR					[illegible]
NO	LB/HR					35
O_2	LB/HR	[illegible]	5291	36,041		6,007
N_2	LB/HR	3422	17371	118,322		118,477
ASH	LB/HR				1,044	
CARBON	LB/HR				522	
DOLOMITE	LB/HR				174	
TOTAL - LBS/HR		26,942	44,[illegible]76	156,428	1,740	177,283
TEMP. - °F		AMBIENT	AMBIENT	500	1600	1650
PRESSURE - PSIA				173		170
DENSITY LBS/CF				0.480		0.225
MOL WT [illegible]		28.8	28.8	28.[illegible]		30.5
MOL/HR [illegible]		473.7	789.5	5466.7		[illegible]
MMSCFD [illegible]		4.32	7.20	49.86		53.82
SP. GR (LIQ.)						
GPM (HOT)						

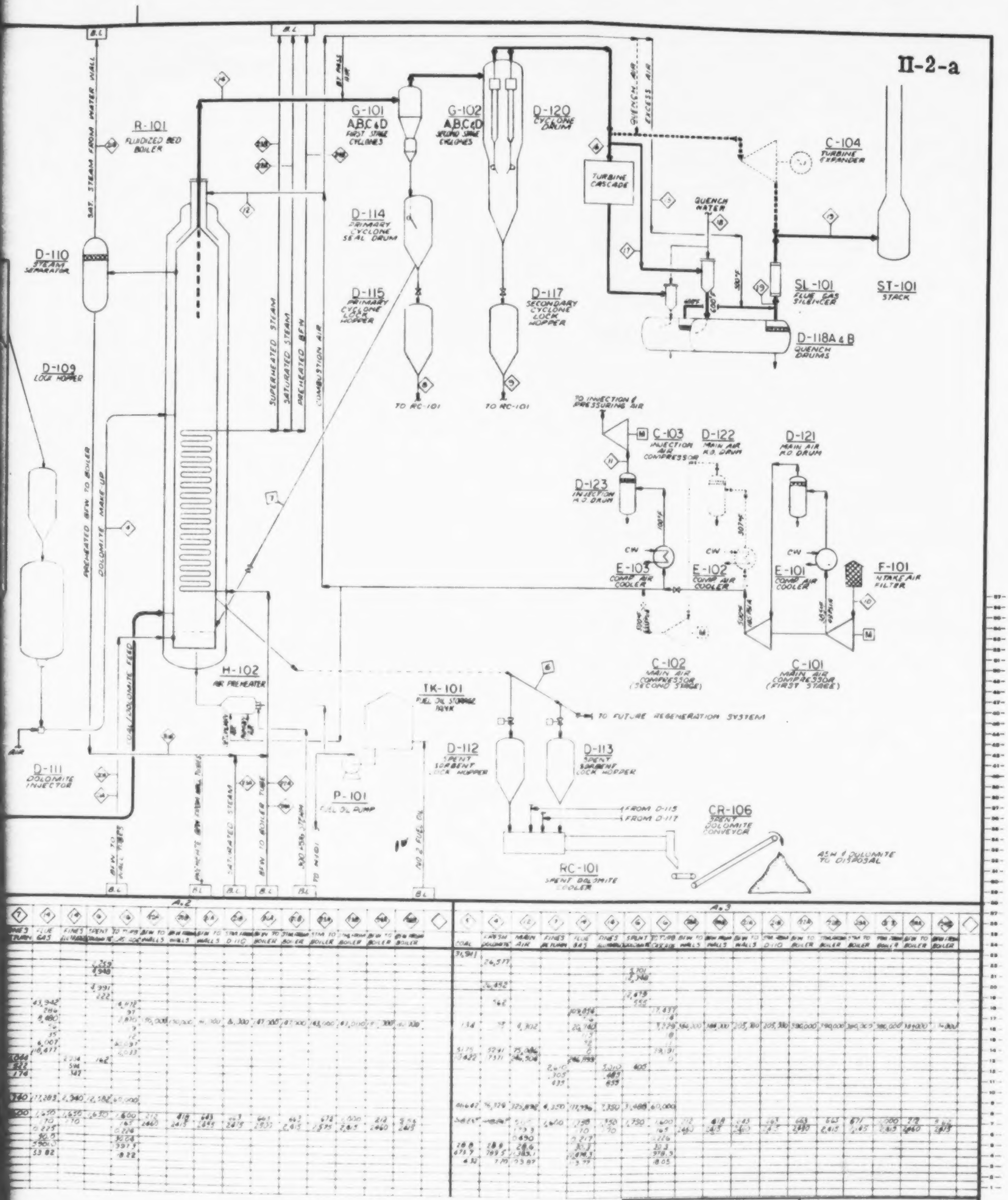
NOTES:

1. STREAM Nº 1 COAL FEED RATE REPRESENTS AVERAGED THROUGHPUT OVER 24 HOUR PERIOD.
2. STREAM Nº 6 FLUE GAS TO C-104 EXCLUDES QUENCH AIR IF REQUIRED.
3. FOR STREAM DATA NOT LISTED IN THIS DWG. CAN BE FOUND IN TABLES FOR MATERIAL BALANCE.
4. EQUIPMENT IN DOTTED LINES REFERS TO FUTURE FACILITIES.

BRUNING 44-512 10187

B

II-2-a



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PROCESS FLOW DIAGRAM
PRESSURIZED FLUIDIZED BED BOILER
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PENNSYLVANIA

DRAWN BY | SCALE | EST. NO. 11-52331 | DWG. NO. OP-721-433 C

Figure II:

II. Description of Plant (continued)

1. Description of Flow (continued)

b) (continued)

this portion of air is dried to -40°F. dew point.

c) By-pass air to Cyclone, G-101, to maintain the cyclone efficiency required.

d) Excess air from the unit which will be vented for the Stack, ST-101.

Combustion air enters from the top of the boiler. This air will also be used to protect part of the discharge line and unprotected portion of the boiler from high temperature. The air then enters from the bottom of the boiler through a grid plate. The grid is equipped with perforated nipples which divert the air downward to cool the grid plate. Four (4) coal injection nozzles enter from opposite sides of the wall tubes.

Three (3) ignition guns are provided above the grid for startup. In addition, an Air Preheater, H-102, has been provided. The preheater will raise the bed temperature to 1000 to 1200°F. to initiate the coal combustion. The preheater, as well as the ignitors, will be taken out of service as the bed temperature is established.

The heat generated in the boiler will be removed by the horizontal tubes bundle as well as the wall tubes through either boiler feed water preheat, steam superheating or evaporator. Steam generation in the horizontal tube bundle is based on a once-through boiler principle. Steam generation in the wall tubes can be on either a once-through or a forced circulation principle. A Steam Drum, D-110, has been provided to separate the steam from boiler feed water as required.

Three (3) horizontal tube bundles will be provided designed for 60%, 100% and 150% of the normal capacity which corresponds to cases A-2, A-1, A-3. In addition, a single-loop test coil will also be provided for

II. Description of Plant (continued)

1. Description of Flow (continued)

various testing purposes. The test loop will be designed to test metallurgy under conditions of erosion, corrosion and severe temperatures. Heat transfer can also be tested under conditions of nucleate and film boiling.

The fluidized medium in the boiler consists essentially of dolomite with a small amount of coal. At proper operating temperature, about 90% of the SO_2 generated by the coal combustion will be picked up by the dolomite in the form of calcium sulfate ($CaSO_4$). To maintain a high efficiency of SO_2 removal the dolomite requirement is greater than stoichiometric. The required fresh dolomite is fed from top of the bed at a carefully controlled feed rate to meet the required calcium to sulfur mol ratio. Spent dolomite from the unit is withdrawn from the bottom of the bed to the Spent Dolomite Lock Hopper, D-112 or 113. The dolomite withdrawal is controlled by the boiler fluidized bed level controller which regulates one of the two operating slide valves to the spent dolomite lock hopper. A bed level recorder has been provided at the lower section of the boiler. This recorder is used for continuous monitoring of the dolomite bed density and height.

The disengaging space above the boiler bed can be adjusted by extending part of the outlet pipe into the dilute phase. The flue gas with its entrained dust will be directed to the First-State Cyclones, G-101 A, B, C or D, where over 88% of the dust is recovered. Due to the various operation modes of the boiler, two of the four cyclones are equipped with spool pieces whereby one or two cyclones may be taken out of service to maintain the recovery efficiency. At normal operating conditions the inlet velocities to these cyclones are approximately 54 fps. It is possible to operate the cyclones at 75% of rated capacity without appreciable loss of efficiency.

TABLE I

PRIMARY CYCLONE EFFICIENCY

Dust removing efficiency is a function of particle size and for a given dust size range it is also a function of velocity. The following variation in dust removal efficiencies was received from Ducon for various capacities:

Capacity % of Max.	Inlet Velocity FPS	Dust Removal Est. Eff. %
100	53.5	89.60
75	40.1	88.67
5	26.7	85.28

II. Description of Plant (continued)

1. Description of Flow (continued)

When the capacities are further reduced, provision has been made to introduce by-pass air to the cyclones to maintain the proper velocity at turndown.

The dust recovered from the cyclones will be directed to the Primary Cyclone Seal Drum, D-114. When this drum reaches its high level it will discharge the dust to the Primary Cyclone Lock Hopper, D-115, through a series of interlocked valves. When D-114 reaches its low level, its outlet valve will be shut to maintain a minimum level. The solid accumulated in D-115 will then be discharged to the Spent Dolomite Cooler, RC-101.

The effluent from Cyclones, G-101, will be forwarded to the Cyclone Drum, D-120. The cyclone drum contains four (4) Second-Stage Cyclones, G-102A, B, C & D. Again, two of the four cyclones will be fitted with spool pieces so that one or more cyclones can be taken out of service to suit the mode of operation. When D-120 is full, the dust will flow to the Secondary Cyclone Lock Drum, D-117, through a series of interlocked valves. The solids in D-117 are then weighed and discarded to the spent dolomite cooler.

The flue gas from G-102 cyclones are then divided into two streams. Part of the flue gas will go to the Turbine Cascade unit. The main purpose of this unit is for erosion and high temperature tests of various types of turbine blades. Due to the presence of CO and coal dust in the flue gas, the flue gas temperatures may be as high as 2000°F. as a result of after-burning. The flue gas is quenched by water to 600°F. or less,before discharging to the Quench Drum, D-118B.

The remaining flue gas stream is also quenched to 600°F. The boiler

II. Description of Plant (continued)

1. Description of Flow (continued)

back pressure controller is located on this stream downstream of D-118A. The effluents from D-118A & B is forwarded to the Flue Gas Silencer, SL-101 and finally to the stack.

Spent dolomite discarded from D-112 or 113, and flyash from D-115 and D-117 will be forwarded to the rotary Spent Dolomite Cooler, RC-101. The waste matter will be cooled to approximately 300^oF and discarded via the Spent Dolomite Conveyor, CR-106.

TABLE II

MATERIAL BALANCE
Case A-1

Stream No.	Description	Temp. °F	Pressure psia	Flow Rate lb/hr	Composition		Particle Size
1	Wet coal from BL	Ambient	15	120,000(*)	Moisture	10.0 wt.%	1½"x0
					VCM	36.8 "	
					Fixed Carbon	45.3 "	
					Ash	7.9	
					Total	100.0	
2	Sized Coal	100	15	111,240(*)	C	71.3 wt.%	¼" x 0
					H	5.4 "	
					O	9.3 "	
					N	1.3 "	
					S	4.3 "	
					Ash	8.5 "	
					Total	100.0	
3	Dolomite	Ambient	15	150,000(*)	$CaCO_3$	49.59 wt.%	¼" x 28 mesh
					$MgCO_3$	49.36 "	
					Inerts	1.05 "	
					Total	100.00	
4	Dolomite	Ambient	15	35,728	Same as Stream 3		¼" x 28 mesh
5	Coal to R-101	Ambient	176.4 min.	22,000	Same as Stream 2		¼" x 0
6	Spent Dolomite	1600	176.4	20,979	$CaSO_4$	18.0 wt.%	¼" x 0
					CaO	39.3 "	
					MgO	39.6 "	
					Inerts	1.8 "	
					Ash	1.3 "	
					Total	100.0	
7.	Fines Discarded	1600	165	2900	Ash	60.0 wt.%	
					Carbon	30.0 "	
					Dolomite	10.0 "	
					Total	100.0	

TABLE II

MATERIAL BALANCE (continued)

Case A-1

Stream No.	Description	Temp. °F	Pressure psia	Flow Rate lb/hr	Composition	Particle Size
8.	Fines Discarded	1600	165	1432	Same as Stream 7	
9.	Fines Discarded	1600	165		Same as Stream 7	

(*) Flow rate based on 40 hr. operation per week

TABLE II

MATERIAL BALANCE (continued)
Case A-1

Stream No.	Description	Temp °F	Pressure psia	Flow Rate		Composition		Dust Loading gr/ACF
				lb/hr	MMSCFD			
10	Air to C-101	Ambient	14.3	366,504	116.8	O_2	20.6 M %	
						N_2	77.3 "	
						H_2O	2.1 "	
						Total	100.0	
11	Air to C-103	100	180	53,500	17.0	O_2	21.0 M %	
						N_2	79.0 "	
						H_2O	nil	
						Total	100.0	
12	Air to R-101	500	175	238,988	76.17	Same as Stream 10		
13	Air By-passed	500	175	73,611	23.46	Same as Stream 10		
14	Flue Gas from R-101	1600	168	273,737	82.8	CO_2	18.3 M %	20.8
						CO	0.2 "	
						H_2O	8.5 "	
						O_2	1.7 "	
						N_2	71.2 "	
						SO_2	148 ppm	
						NO	198 ppm	
15	Flue Gas from G-101	1600	165	273,737	82.8	Same as Stream 14		~3.01
16	Flue Gas to Turb. Cascade	1600	165	60,000	18.1	Same as Stream 14		~ 0.30
17	Flue Gas to Quench	1600	165	213,737	64.7	Same as Stream 14		~ 0.30
18	Quench Water	200	185	65,683	131 gpm			
19	Flue Gas to SL-101	600	Atm	339,420	116.1	CO_2	11.5 M %	~ 0.30
						CO	0.12 "	
						H_2O	42.9 "	
						O_2	1.1 "	
						N_2	44.4 "	
						SO_2	92 ppm	
						NO	124 ppm	

TABLE III

HEAT BALANCE

around

Fluidized Bed Boiler
Case (A-1)

Datum: 77° F

INPUT

Stream	Lb/Hr	Temp. °F	MM Btu/Hr
Dried Coal	22,000	77	
Sen. Ht			0
Chemical (LHV)			275.0
Comb. Air	238,988	500	24.98
Fresh Dolomite	35,728	77	0
Fines Returned	2,900	1600	1.13
Total Input	299,616		301.11

OUTPUT

Stream	Lb/Hr	Temp. °F	MM Btu/Hr
Flue Gas	273,737	1650	119.4
Spent Dolomite	20,979	1650	8.1
Fines Elutriated	4,900	1650	1.9
Reaction Heats			
Reactions with Dolomite			
$CaCO_3 + SO_2 + \frac{1}{2}O_2 = CaSO_4 + CO_2$			-3.91
$CaCO_3 = CaO + CO_2$			11.4
$MgCO_3 = MgO + CO_2$			10.58
No Formation			
$\frac{1}{2}N_2 + \frac{1}{2}O_2 = NO$			0.07
Incomplete Coal Combustion			
$CO_2 = C + O_2$			1.69
$CO_2 = CO + \frac{1}{2}O_2$			2.08
Heat Loss			0.20
Total Output	299,616		151.51

Heat Available for Steam Generation = 301.11 - 151.51
= 149.6 MM Btu/Hr

Form No. 130-135

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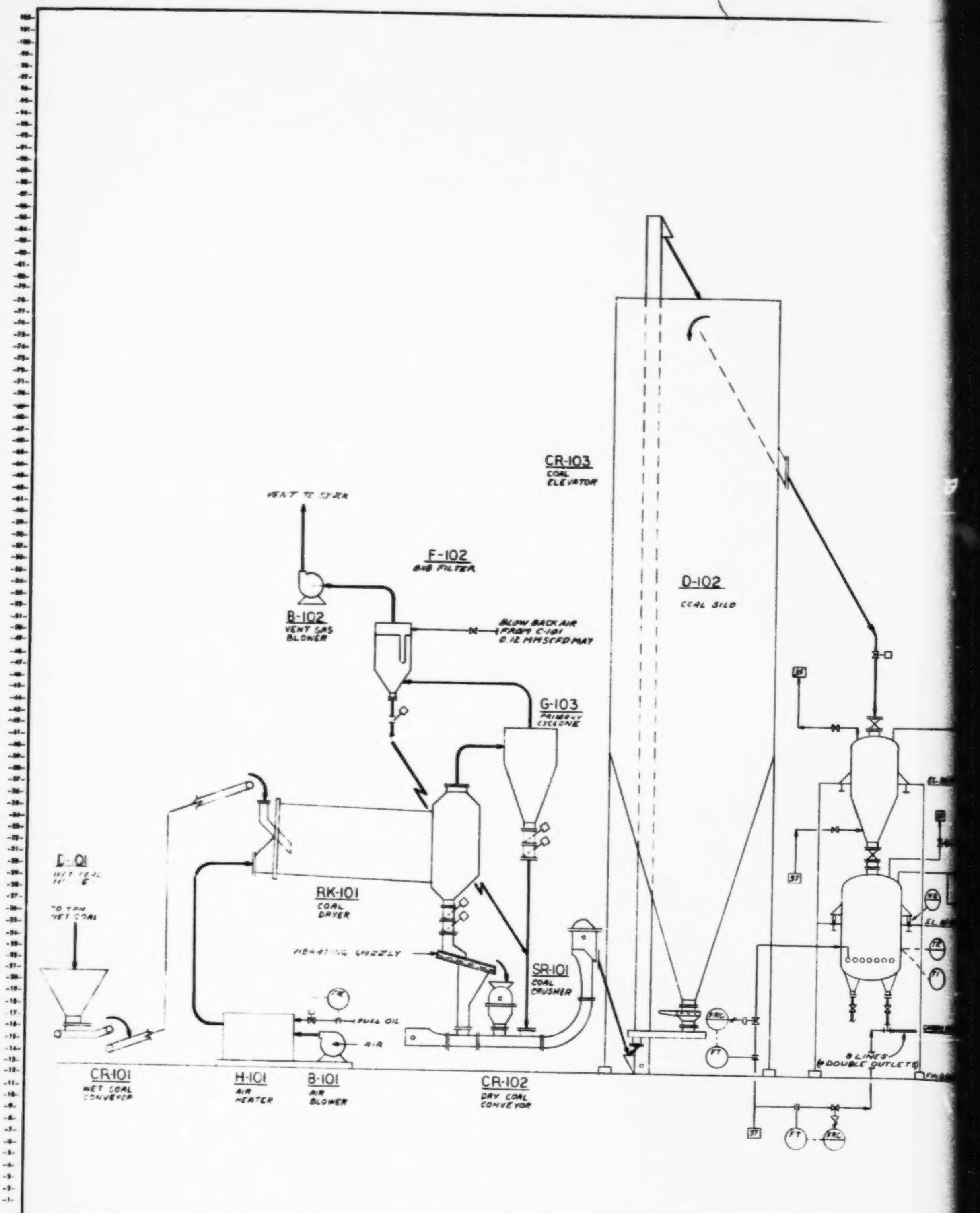
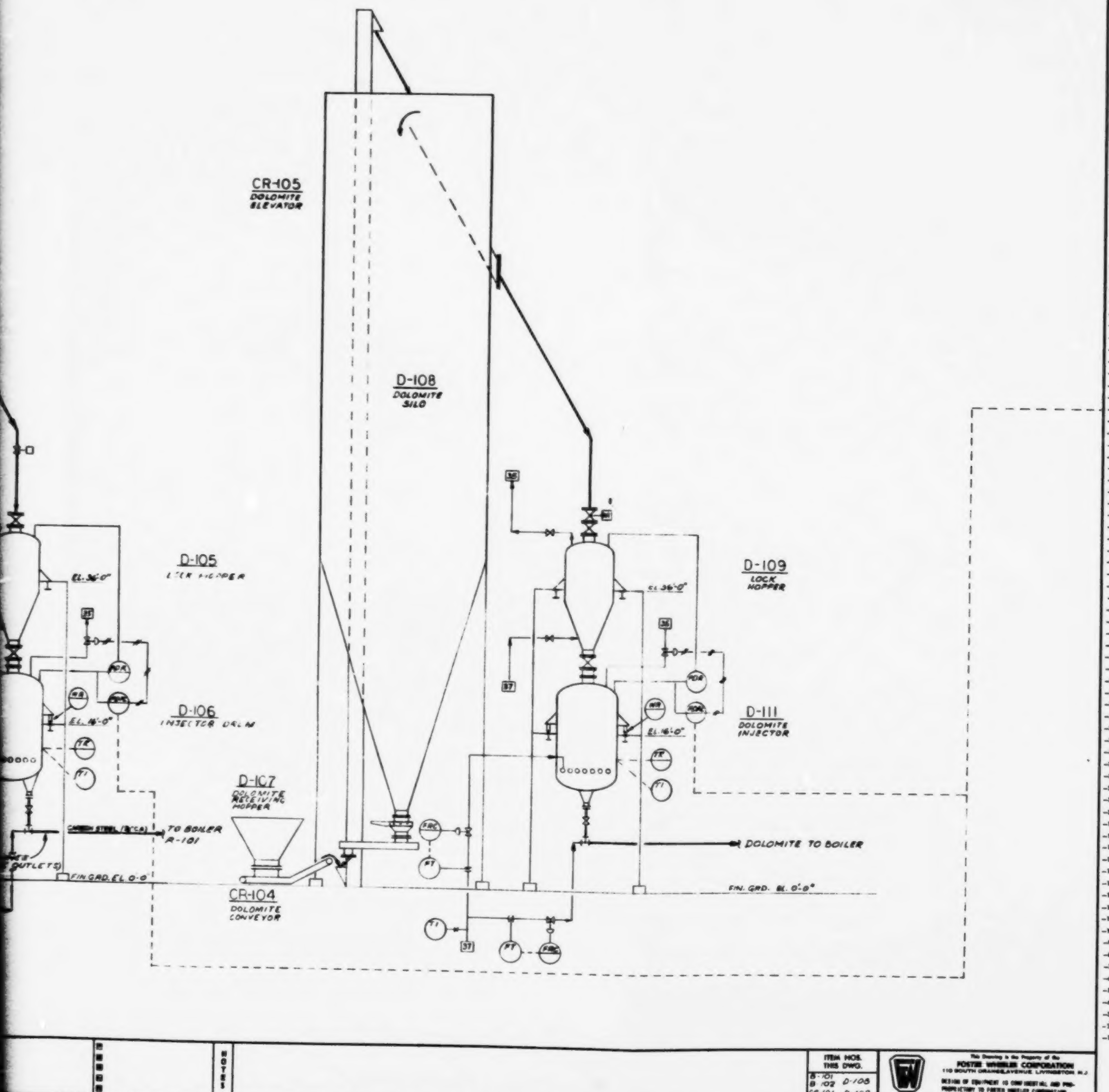


LEGEND

- COOLING WATER SUPPLY
- COOLING WATER RETURN
- # H.P. STEAM
- # STEAM (INTERMEDIATE PRESS.)
- # L.P. STEAM
- # EXHAUST STEAM
- POTABLE WATER
- PLANT AIR
- INSTRUMENT AIR
- H.P. CONDENSATE
- CONDENSATE
- TREATED WATER
- FUEL OIL
- FUEL GAS
- CLEAN WATER SEWER
- OILY OR DIRTY WATER SEWER
- PROCESS SEWER
- SANITARY SEWER
- FIRE WATER
- FLUSHING OIL
- PUMPOUT
- PURGE GAS
- BLOWDOWN
- FLARE
- TO ATMOSPHERE
- INERT GAS
- INJECTION AIR

ITEM NO.			CR-101	CR-102	CR-103	CR-104	CR-105	H-101	B-101	B-102	ITEM NO.						RK-101
SERVICE			WET COAL CONVEYOR	DRY COAL CONVEYOR	COAL ELEVATOR	DOLOMITE CONVEYOR	DOLOMITE ELEVATOR	AIR HEATER	AIR BLOWER	WET GAS BLOWER	SERVICE						COAL DRYER
RATED A.																	
			CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	MATERIAL						CARBON STEEL
CORR. ALL								REFRACTORY LINED	1/8"	1/8"	CORR. ALL.						1/8"
INSULATION											INSULATION						
REVISIONS																	

B



ITEM NO.	RH-101	SR-101	F-102	G-103	D-101	D-102	D-105	D-106	D-107	D-108	D-109	D-111
SERVICE	COAL DRYER	COAL CRUSHER	BAG FILTER	PRIMARY CYCLONE	WET COAL HOPPER	COAL SILO	LOCK HOPPER	INJECTOR DRUM	DOLOMITE RECEIVING HOPPER	DOLOMITE SILO	LOCK HOPPER	DOLOMITE INJECTOR
SIZE												
DES. PRESS TEMP												
OPER. PRESS TEMP												
MATERIAL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL
CORR. ALL.	1/8"		1/16"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"
INSULATION												

REVISIONS

NOTES

ITEM NOS. THIS DWG.	
B-101	
B-102	D-108
CR-101	D-109
CR-102	D-111
CR-103	F-102
CR-104	G-103
CR-105	H-101
D-101	RH-101
D-102	SR-101
D-105	
D-106	
D-107	

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ENGINEERING FLOW DIAGRAM
PROPOSED COAL PREPARATION AND
INJECTION SYSTEM
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PENNSYLVANIA

REF. NO.
DRAWN BY: Z.C. 8-23-72 SH. 1 OF 3
CONTRACT NUMBER 11-52 331 DWG. NO.-OP-721-423 C

Figure III-a

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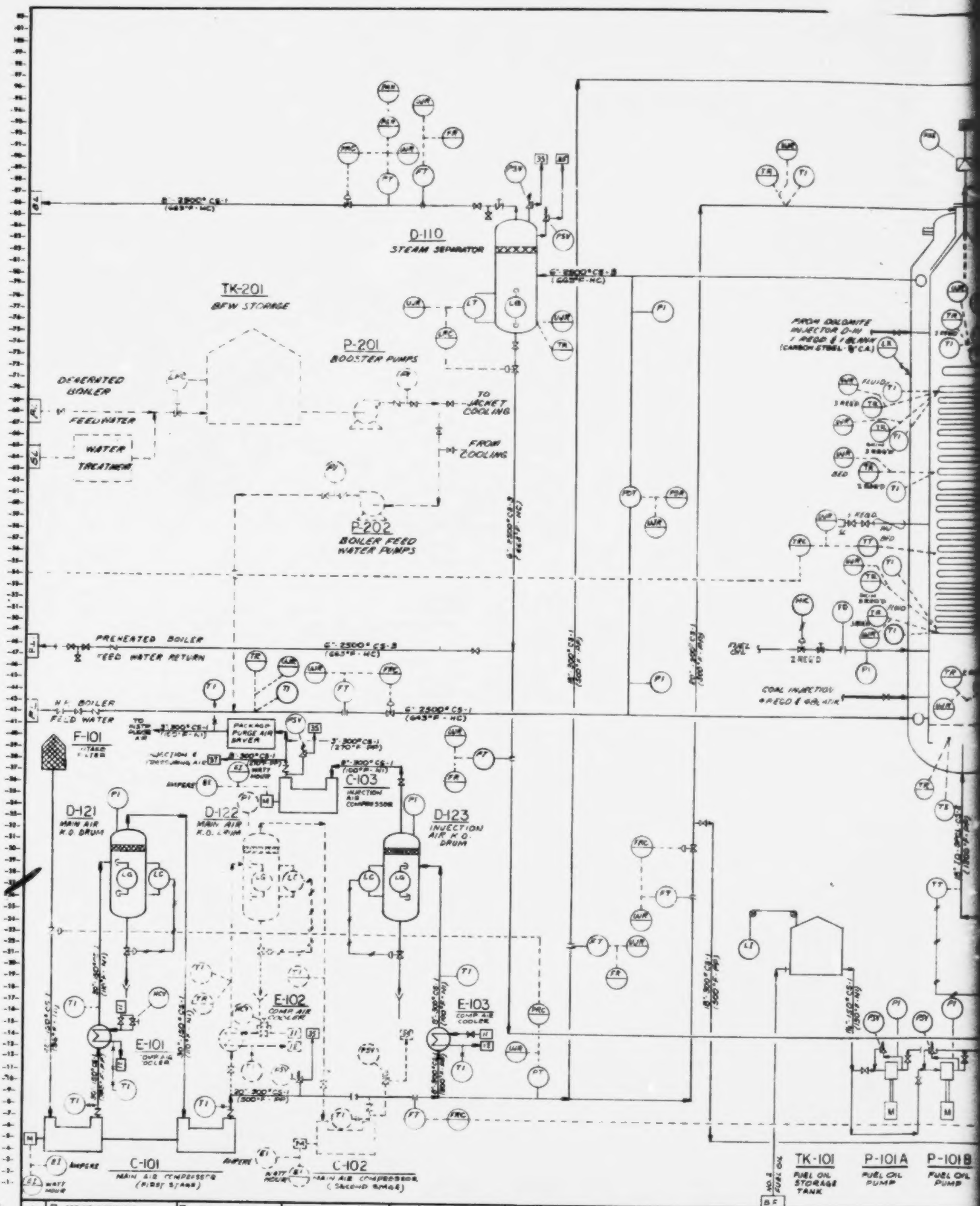

LEGEND

- COOLING WATER SUPPLY
- COOLING WATER RETURN
- # H.P. STEAM
- # STEAM (INTERMEDIATE PRESS.)
- # L.P. STEAM
- # EXHAUST STEAM
- POTABLE WATER
- PLANT AIR
- INSTRUMENT AIR
- H.P. CONDENSATE
- CONDENSATE
- TREATED WATER
- FUEL OIL
- FUEL GAS
- CLEAN WATER SEWER
- OILY OR DIRTY WATER SEWER
- PROCESS SEWER
- SANITARY SEWER
- FIRE WATER
- FLUSHING OIL
- PUMPOUT
- PURGE GAS
- BLOWDOWN
- FLARE
- TO ATMOSPHERE
- INERT GAS
- INJECTION AIR

ITEM NO.	P-101A	P-101B							C-101	C-103
SERVICE	FUEL OIL PUMP	FUEL OIL PUMP							MAIN AIR COMPRESSOR	INJECTION AIR COMPRESSOR
S.G. AT P.T.										
DES. GPM AT P.T.	~	SPARE							121.5 MMSCFD	17.0 MMSCFD
DES. DIFF. PSI	450	FOR							170.3	480.7
MAX DISCH P.S.I.G.	450	P-101A							85 PSIA	465 PSIA
MATERIAL	CARB ST. (⅛ CA)								CARB. STL. (⅛ CA)	CARB. STL. (⅛ CA)
INSULATION	NI								NI	NI

ITEM NO.	E-101	E-103				
SERVICE	COMPRESSOR AIR COOLER	COMPRESSOR AIR COOLER				
SHELL DES. P & T.	75° @ 435°F	200° @ 600°F				
TUBE DES. P & T.	75° @ 160°F	75° @ 180°F				
SURFACE	9700 SQ FT	964 SQ FT				
MAT'L SHELL	CARB. STL. (⅛ CA)	CARB. STL. (⅛ CA)				
MAT'L TUBE	CARB. STL. (⅛ CA)	CARB. STL. (⅛ CA)				
INSULATION	NI	NI				

REVISIONS

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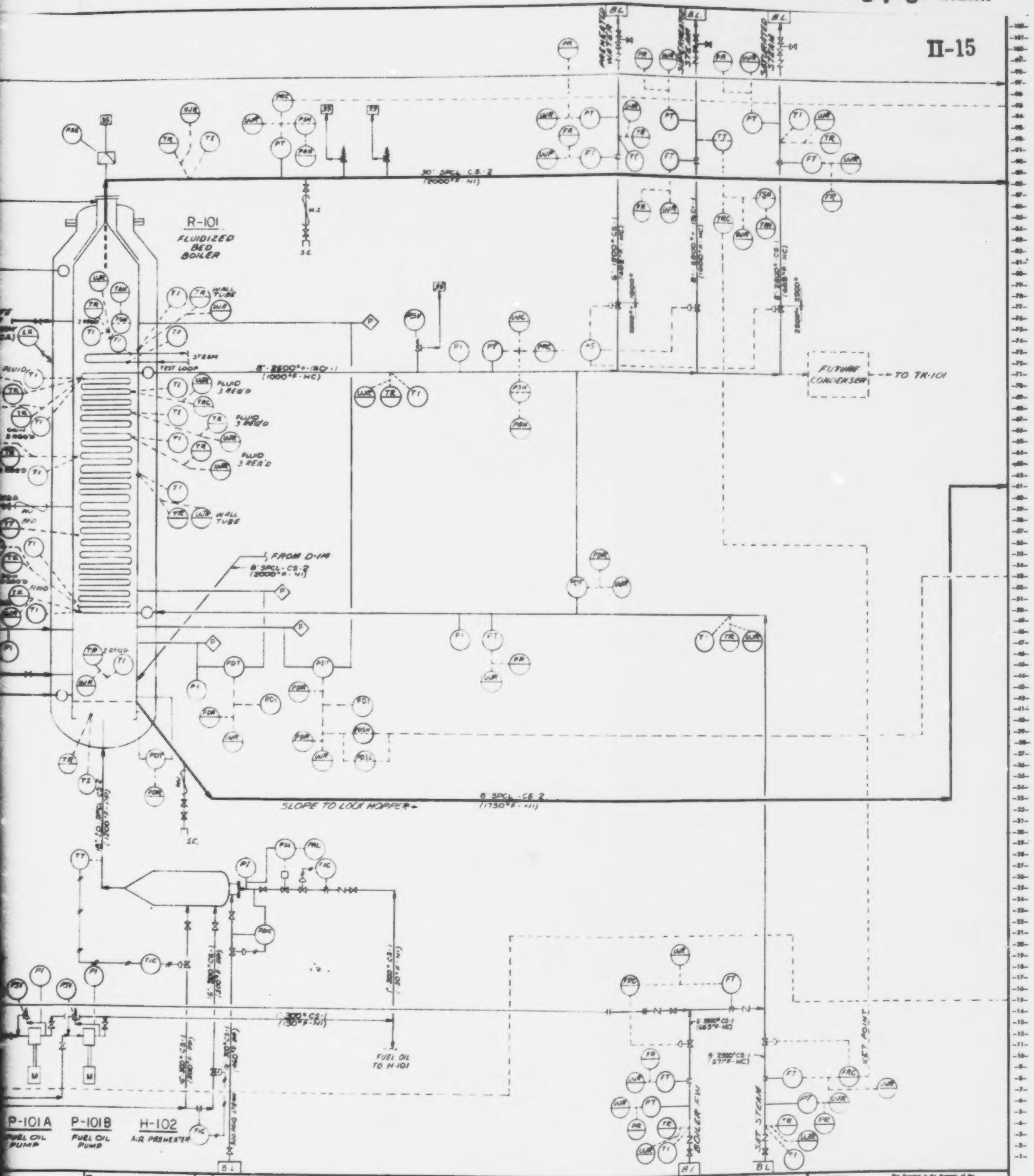


NOTES

- STARTUP LINE
- (F) = INSTRUMENT PURGE AIR
- (LWR) = COMPUTER MONITORING AND/OR DATA LOGGER
- WJ WATER JACKET
- SC SAMPLE CONNECTION
- EQUIPMENT IN DOTTED LINE REFER TO FUTURE FACILITIES.

F-101	H-102	ITEM NO.	D-110	D-121	D-123	R-101	TK-101
INTAKE FILTER	AIR PREHEATER	SERVICE	STEAM SEPARATOR	MAIN AIR KNOCK OUT DRUM	INJECTION AIR KNOCK OUT DRUM	PRESSURIZED FLUIDIZED BED BOILER	FUEL OIL STORAGE TANK
		SIZE	4'0"D-6'0"	12'0"D-15'0"	3'0"D-2'0"	2'0"D-66'5"	
		DES. PRESS-TEMP	2750°@700°F	40#@435°F	347#@150°F		
		OPER PRESS-TEMP	2500°@668°F	34.3#@ 0°F	315#@100°F	320#@900°F	
				(385°F MAX)			
		MATERIAL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL
		INSULATION	HC	NI	NI	HC	NI

ITEM NOS. THIS DWG.

C-101
C-103
D-110
D-121
D-123
E-101
E-103
F-101
H-102
P-101 A/B
R-101
TK-101

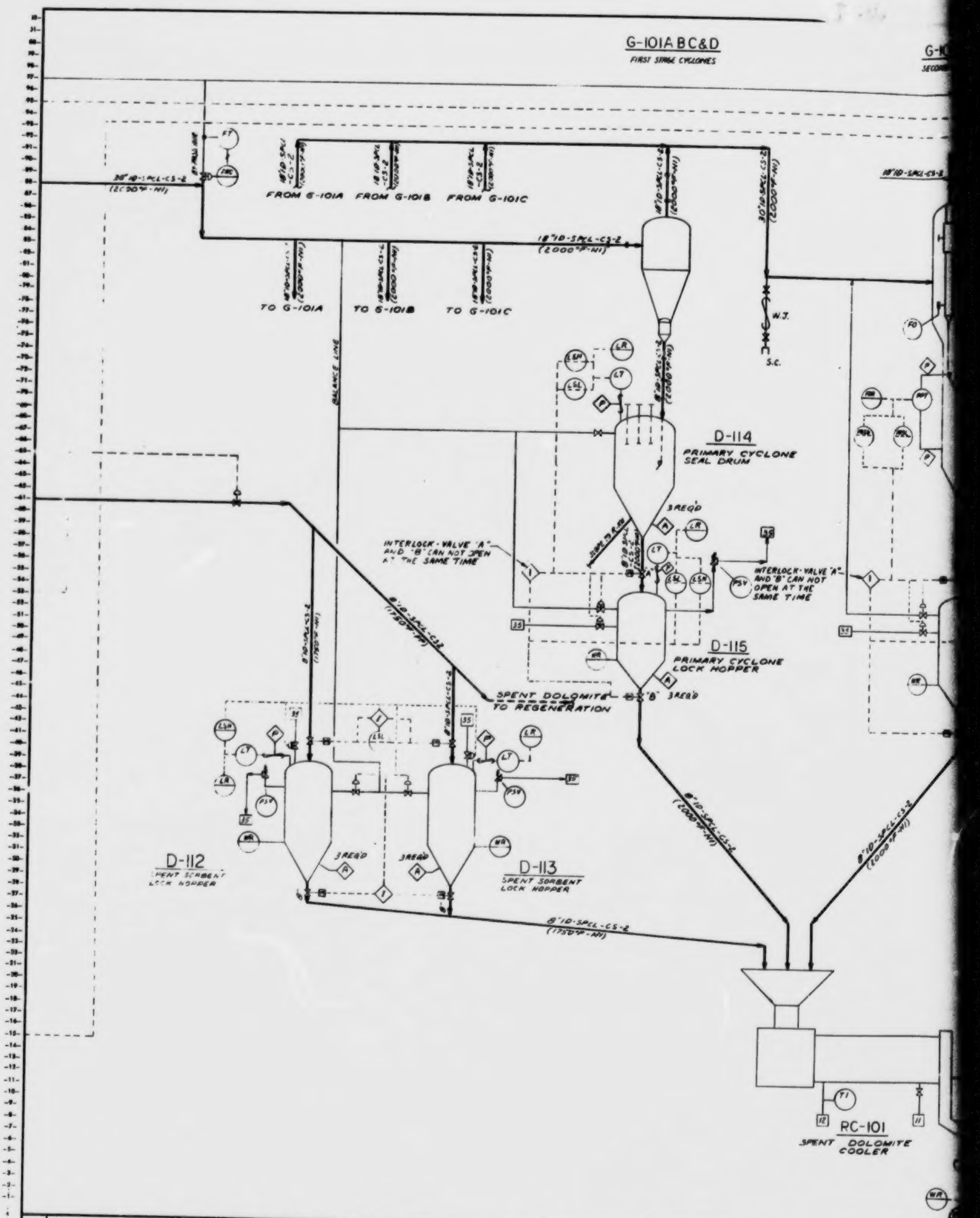
This Drawing is the Property of the
FOSTER WHEELER CORPORATION
110 SOUTH ORANGE AVENUE, LIVINGSTON, N.J.
DETAIL OF EQUIPMENT IS CONFIDENTIAL AND PROPRIETARY TO FOSTER WHEELER CORPORATION, WESTINGHOUSE ELECTRIC CORPORATION AND THE UNITED STATES GOVERNMENT.

ENGINEERING FLOW DIAGRAM
PRESSURIZED FLUIDIZED BED BOILER
FOR
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PENNSYLVANIA

DRAWN BY R.A.C. 6-2-72 SH 2 OF 2
CONTRACT NUMBER 11-5233I
DWG. NO. -OP-721-424 C

Figure III-b

A


G-101A B C&D
FIRST STAGE CYCLONES
G-10
SECON
30"ID-SPCL-CS-2 (2000°F-NI)
FT
FRC
18"ID-SPCL-CS-2
FROM G-101A
FROM G-101B
FROM G-101C
18"ID-SPCL-CS-2 (2000°F-NI)
30"ID-SPCL-CS-2 (2000°F-NI)
TO G-101A
TO G-101B
TO G-101C
W.J.
S.C.
BALANCE LINE
LSH
LSL
LR
LT
D-114
PRIMARY CYCLONE SEAL DRUM
3 REQ'D
INTERLOCK - VALVE "A" AND "B" CAN NOT OPEN AT THE SAME TIME
PSV
35
D-115
PRIMARY CYCLONE LOCK HOPPER
"B" 3 REQ'D
SPENT DOLOMITE TO REGENERATION
8"ID-SPCL-CS-2 (1750°F-NI)
8"ID-SPCL-CS-2 (2000°F-NI)
WR
D-112
SPENT SORBENT LOCK HOPPER
D-113
SPENT SORBENT LOCK HOPPER
RC-101
SPENT DOLOMITE COOLER
TI
12
11
FO
PT
18"ID-SPCL-CS-2

LEGEND

- COOLING WATER SUPPLY
- COOLING WATER RETURN
- # H.P. STEAM
- # STEAM (INTERMEDIATE PRESS.)
- # L.P. STEAM
- # EXHAUST STEAM
- POTABLE WATER
- PLANT AIR
- INSTRUMENT AIR
- H P CONDENSATE
- CONDENSATE
- TREATED WATER
- FUEL OIL
- FUEL GAS
- CLEAN WATER SEWER
- OILY OR DIRTY WATER SEWER
- PROCESS SEWER
- SANITARY SEWER
- FIRE WATER
- FLUSHING OIL
- PUMPOUT
- PURGE GAS
- BLOWDOWN
- FLARE
- TO ATMOSPHERE
- INERT GAS
- INJECTION AIR LINE

ITEM NO.									SL-101	CR-106
SERVICE									FLUE GAS SILENCER	SPENT DOLOMITE CONVEYOR
S.G. AT P.T.										
DES. G.P.M. AT P.T.										
DES. DIFF. P.S.I.										
MAX DISCH. P.S.I.G.										
MATERIAL										
INSULATION									CARB. STL (& C.A.)	CARBON STEEL
REVISIONS										

ITEM NO.							
SERVICE							
SHELL DES. P. & T.							
TUBE DES. P. & T.							
SURFACE							
MAT'L SHELL							
MAT'L TUBE							
INSULATION							

FORM 120 29C REV

B

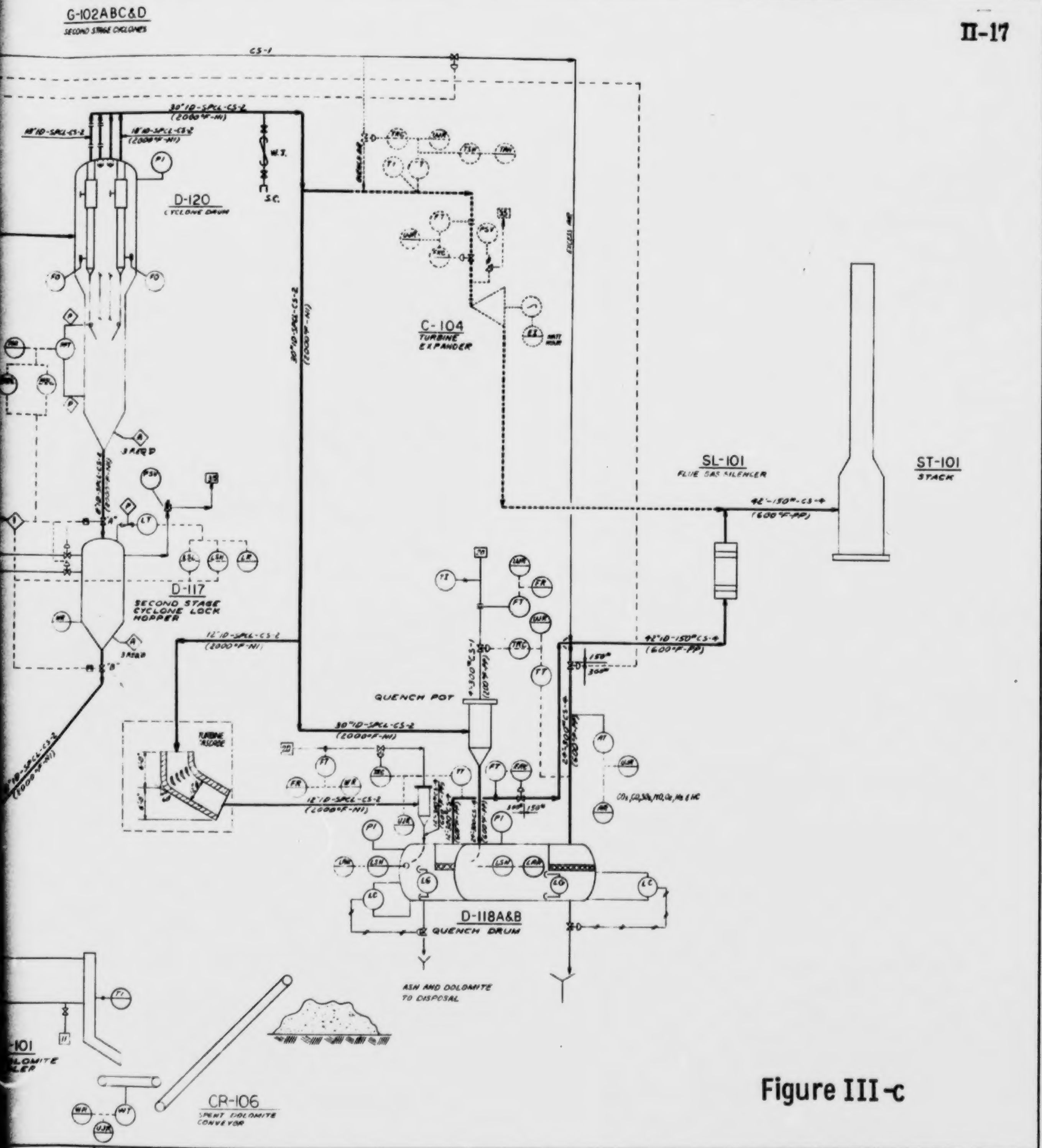


Figure III-c

NOTES

(P) = INSTRUMENT PURGE AIR

(A) = AERATION AIR

(WR) = COMPUTER MONITORING AND/OR DATA LOGGING

EQUIPMENT IN DOTTED LINE REFERS TO FUTURE FACILITY.

		G-101A/B/C/D FIRST STAGE CYCLONES	G-102A/B/C/D SECOND STAGE CYCLONES	RC-101 SPENT DOLOMITE COOLER
		CARB STL/REFR LINE	HASTALLOY "X"	CARB STL/B CR

ITEM NO.	D-112	D-113	D-114	D-115	D-117	D-118A	D-118B	D-120	ST-101
SERVICE	SPENT SORBENT LOCK HOPPER	SPENT SORBENT LOCK HOPPER	PRIMARY CYCLONE SEAL DRUM	PRIMARY CYCLONE LOCK HOPPER	SECONDARY CYCLONE LOCK HOPPER	QUENCH DRUM	QUENCH DRUM	CYCLONE DRUM	STACK
SIZE	6'-6" ID×12'-0"	6'-6" ID×12'-0"	6'-6" ID×12'-0"	6'-6" ID×12'-0"	6'-6" ID×12'-0"	9'-0" ID×17'-0"	9'-0" ID×10'-0"	15'-3" ID×6'-6"	
DES. PRESS-TEMP	320# @ 650°F	320# @ 650°F	320# @ 650°F	320# @ 650°F	320# @ 650°F	320# @ 650°F	320# @ 650°F	320# @ 650°F	
OPER. PRESS-TEMP	155# @ 1750-2000°F	155# @ 1750-2000°F	155# @ 1600-2000°F	155# @ 1600-2000°F	155# @ 1600-2000°F	150# @ 600°F	150# @ 600°F	155# @ 2000°F	
	(INTERNAL LINING)	(INTERNAL LINING)	(INTERNAL LINING)	(INTERNAL LINING)	(INTERNAL LINING)			(INTERNAL LINING)	
MATERIAL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARBON STEEL	CARB STL/B CR
INSULATION	NI	NI	NI	NI	NI	HC	NI	NI	

ITEM NOS. THIS DWG.

CR-106
D-112
D-113
D-114
D-115
D-117
D-118 A/B
D-120
G-101A/B/C/D
G-102A/B/C/D
RC-101
SL-101
ST-101

This Drawing is the Property of the
FOSTER WHEELER CORPORATION
110 SOUTH ORANGE AVENUE, LIVINGSTON, N.J.
DESIGN OF EQUIPMENT IS CONFIDENTIAL AND PROPRIETARY TO FOSTER WHEELER CORPORATION AND THE UNITED STATES GOVERNMENT.

ENGINEERING FLOW DIAGRAM
SPENT SOLIDS LET DOWN
AND TURBINE TEST RIGS
WESTINGHOUSE RESEACH LABORATORY
PITTSBURGH PENNSYLVANIA

EST. NO.		DRAWN BY: A.C.	8-31-76	SH 3 OF 3
CONTRACT NUMBER	11-52331	DWG. NO. -OP-721-426		B

THIS DRAWING SUPERSEDES

III. Basis of Design

A pressurized fluidized bed boiler has been designed to demonstrate the possibility of pressurized fluidized bed steam generation while decreasing pollution from the combustion of high sulfur coal. For this study, an Ohio Pittsburgh No. 8 Seam coal will be burned at a normal rate of 22,000 lbs/hr with 10% excess air. The crushed coal is injected into a fluidized bed consisting of particles of 28 mesh to ¼" dolomite. The ash formed after combustion is less dense than the dolomite and is elutriated out of the bed. Specifications for the coal and dolomite are given in Tables V and VI.

Three boiler load conditions, heat and material balances have been calculated for corresponding to 60%, 100% and 150% of normal coal rate as indicated in Table IV Basis of Design. The tubes for steam generation in the fluidized bed can be operated in the preheat, evaporation or superheat mode. The water wall tubes can be operated in the preheat and evaporation mode. It is also possible to operate the boiler to sequentially preheat, evaporate and superheat by supplying boiler feed water preheated to 550°F. to the water walls and further penetrating water in the water wall tube to 672°F. The preheated water is then evaporated and superheated in the coils in the fluidized bed tubes. The superheat section can also operate as a reheat section as the temperature profile is the same but reheat pressure is lower than superheat pressure.

Equipment has been designed to supply sufficient fresh dolomite charge for a maximum calcium to sulfur mole ratio of 6 to 1 or a regenerated dolomite circulation rate to provide a maximum of 10 to 1 mole ratio of calcium to sulfur, with makeup of fresh dolomite set at 10% of the regenerated dolomite rate.

TABLE NO.IV

PRESSURIZED FLUIDIZED BED COMBUSTION BOILER

Basis of Design

Case No.	A-1	A-2	A-3*
Load Factor % of Normal	100	60	150
Coal Injection Rate (as rec.) lb/hr	22,000	13,200	33,000
Excess Air %	10	20	0
Dolomite Injection Rate lb/hr	35,728	21,437	53,592
Mol Ratio Ca/S	6/1	6/1	6/1
Combustion Air Rate lbs/hr	238,988	156,428	325,892
Flue Gas Rate lbs/hr	273,737	177,283	377,966
ACFS @ 1650°F & 170 psig	335.0	218.9	483.9
Superficial Velocity ft/sec	9.19	6.00	13.28
Heat Absorption by Steam MM/Btu/hr	149.6	85.7	222.0

*It is not necessarily intended that case A-3 be operated with zero percent excess air; rather, A-3 conditions indicate the maximum design air, coal and dolomite ratio.

III. Basis of Design (continued)

1. Range of Operating Conditions

The boiler has considerable flexibility built into the equipment specifications. Coal and dolomite can be varied from 10% to 150% of normal flow rates. Fluidized bed heights can be varied from 3 feet to 30 feet. Pressure of the fluidized bed can be varied from atmospheric to 160 psig above the fluidized bed. The boiler shell is designed for future operations of up to 320 psig. Two separate air distribution grids are provided for various capacities from 60% to 150% of normal design. Three separate steam generating coils are provided for 60%, 100% and 150% of normal steam generation. Boiler feed water can enter at 212 to 640°F. with flow rates of up to 500,000 lbs/hr. The combustion air bypass control can accommodate 0 to 100% of the total design capacity of the air compressor.

The fixed parameters are: the use of a single fluidized bed of approximately 35 square feet in cross-section, a steam pressure of 2400 psig and temperature of 1000°F. superheat (when operating in the superheat mode).

2. Site Location

The preferred location of the demonstration boiler is adjacent to a large existing power plant where appropriate tie-ins could be effected for supply of boiler feed water, coal, power and the disposal of ash and steam, either saturated or superheated. Such a location would simplify and reduce the cost of installation of the development boiler.

If it is not possible to locate close to the site of an existing utility, then it will be necessary to provide various auxiliaries to the developmental boiler such as condenser, water purification equipment, boiler feed water storage, as well as feed water pumps, and cooling towers.

III. Basis of Design (continued)

3. Auxiliary Systems

a) Compression

A major auxiliary with respect to cost is the air compression systems. Air is required for combustion, for pneumatic injection, for pressuring lock hoppers and for instrument purges as well as for instrument air. Best economy is obtained by compression of air from atmospheric to 170 psig and 500°F. in a single two-casing centrifugal compressor. Space is provided to install, at a future date, Compressor C-102, motor-driven, to compress air from 170 psig to 320 psig in one stage. A third machine is required to compress transport air from 170 psig to 320 psig (450 psig future) for pneumatic transport. A standby instrument air compressor is supplied to supplement instrument air from the power plant.

b) Coal & Dolomite Injection

Wet coal is received in open hopper cars in the size range of 1½" x 0 per coal specifications indicated in Table V. We have assumed 10% moisture to allow for rain wetting. The cars are unloaded into a hopper under the railroad tracks. The coal is dried to 3% from 10% surface moisture to insure uniform flow and then it is crushed to ¼"x0 and conveyed to a covered silo for storage. Unloading coal is scheduled for 8 hours per day, 40 hours per week at a rate of 120,000 lbs/hr. Coal is injected from the silo by means of a Petrocarb injection system. The Petrocarb system consists of a storage vessel, a pressurizing vessel and an injection vessel. The coal is injected into the boiler by means of 4 injection nozzles. Injection of the maximum rate of 33,000 lbs/hr of ¼"x0 coal requires 3,000 SCFM of pneumatic air when the boiler operates at 160 psig.

COAL SPECIFICATIONS

TABLE V

OHIO PITTSBURGH NO. 8 SEAM COAL

(Source of data: USBM, Pittsburgh Pa.)

SAMPLE: Run of Mine - As received

PROXIMATE ANALYSIS (wt. %):

Moisture	3.3
Volatine Matter	39.5
Fixed Carbon	48.7
Ash	8.5
	100.0

ULTIMATE ANALYSIS (wt. %):
(includes moisture)

C	71.2
H	5.4
O	9.3
N	1.3
S	4.3
Ash	8.5
	100.0

GROSS HEATING VALUE: 13,000 Btu/lb

NET HEATING VALUE: 12,500 Btu/lb

ASH ANALYSIS (wt. %):

SiO_2	45.3
Al_2O_3	21.2
Fe_2O_3	27.3
TiO_2	1.0
P_2O_5	0.11
CaO	1.9
MgO	0.6
Na_2O	0.2
K_2O	1.8
SO_3	0.7
	100.1

COAL DENSITY:

Particle	95 lbs/CF
Bulk	55 "

FUSIBILITY OF ASH:

Initial Deformation Temperature	- 2080°F
Softening Temperature	- 2230°F
Fluid Temperature	- 2420°F

GRINDABILITY (Hardgrove): 50 - 60

FREE SWELLING INDEX: 5 - 5.5

TABLE VI

SORBENT SPECIFICATIONS
Dolomite Properties

Type Dolomite - BCR 1337

Size - Purchased dry and double-screened in size of 1/4" to 28 mesh. (6400 to 580 microns)

Recycle size range due to attrition and elutriation is 600 to 6350 microns with average size of approximately 2000 microns.

Density of 1/4" to 28 mesh

A - Particle - 175 lbs/CF

B - Bulk - 95 lbs/CF

C - Fluidizing 40 lbs/CF @ 6 ft/sec

Chemical Composition Analyzed as Oxide

	Wt. %	Mol %
MgO	45.0	53.00
CaO	53.0	44.84
Misc.	2.0	2.16
	100.0	100.00

Hardness

Moh - 3.5

III. Basis of Design (continued)

3. Auxiliary Systems (continued)

b) Coal & Dolomite Injection (continued)

Dolomite is received crushed and dried in the size range of 28 mesh by ¼" in covered rail cars. The cars are unloaded in a shed by means of a hopper under the tracks and then conveyed to a dolomite silo. From the silo the dolomite is injected into the top of the boiler fluidized bed by means of a Petrocarb Pneumatic Injector.

Spent sorbent is discharged from the lower section of the bed, i.e., just above the grid. The grid may be located in any three positions, from 3 ft. to 7 ft. below the bottom of the tube bundle. Spent sorbent may be discharged at elevations of 2 ft., 4 ft., or 6 ft., 24", 48" or 72" from the bottom of the tube bundle. A view of the coal unloading systems and coal and dolomite silos is shown in Figure 1, the plant perspective drawing, in Section I.

4. Water & Steam Supply & Disposal

Pressures and temperatures for boiler operation were chosen to represent the recent steam generator practice for sub-critical operations. The actual pressures will depend upon the adjacent power company's boiler design. Water and steam are assumed to be available at 2600 psig and at the capacity required in the developmental plant as shown on Drawing OP-721-433C. Saturatated water at 640°F. and 2600 psig would be received from the power plant economizer or heat exchangers. Sub-cooled water at 212°F. and 2600 psig would be received from the power plant deaerators. Saturated steam and 1000°F. superheated steam are returned to the utility company. The pressure drop in the system was purposely kept low (below 110 psi for normal flow) in order to fit into the utility company's

III. Basis of Design (continued)

4. Water & Steam Supply & Disposal (continued)

boiler operating pressure drop. Normally all steam is sent to the utility company's power plant for disposal. Superheated steam may be sent directly to the high pressure turbines. Saturated steam may be sent to intermediate or low pressure turbines or the pressure may be dropped so that the steam can be used for heat exchange.

5. Dolomite and Ash Disposal

Spent dolomite and ash from the bottom of the boiler, as well as ash and carryover removed by cyclones are water-cooled in a rotary cooler to 300°F. from a maximum temperature of 1750°F. in the fluidized bed. Water sprays are provided if additional direct contact cooling below 300°F. is required. The ash is then transported to the power plant by conveyor. Alternately the ash can be slurried and pumped to the power plant's disposal facility for settling. It is necessary to cool the ash as it is conceivable under certain conditions that quantities of unburned char may be released at a high temperature causing the char to burn in the air.

6. Turbine Expander and Test Cascade

A stationary cascade to test turbine blade materials may be provided in the flue gas stream after the cyclones. It is expected that the temperature and pressure of the flue gas will decrease only slightly passing through the test cascade. Space will be provided for future installation, of a small turbine expander to take part or all of the flue gas and recover some of the energy residing in the high temperature and pressure of the gas. Such a turbine expander should be designed to operate with an inlet rated for 1600°F. and 155 psig, and with flow characteristics similar to a commercial utility gas turbine. In order

III. Basis of Design (continued)

6. Turbine Expander and Test Cascade (continued)

to control the pressure at the boiler fluidized bed, a bypass line would be used around an expander operating under pressure control. To keep the pressure control valve from reaching too high a temperature the bypass line with the control valve in it would be quenched to a low temperature. To prevent the flue gas temperature from rising too high about 1600°F., which would limit the life of the expander turbine blades, the flue gas is tempered with cool air (at 500°F.) from the compressor C-101, which air normally bypasses the boiler.

7. Combustion Gas Disposal

Combustion gas from the boiler may be generated at 1600 to 1750°F. and at pressures up to 160 psig (320 psig future). Part or all of the flue gas passes through the test cascade. The flue gas stream is quenched to below 600°F. and the pressure is dropped by means of back pressure control. The flue gas is then sent through a silencer to the stack.

IV. Detailed Boiler Design

1. Boiler Design

The pressurized fluidized bed boiler consists of a single fluidized bed enclosed with a monofin membrane water wall containing a horizontal serpentine heat exchange bundle. The bed and steam generating pressure parts are contained in a 12-foot diameter vessel approximately 78 feet tall designed for 320 psig pressure. Where possible the test facility was designed to duplicate a single module of the original 300 MW Foster Wheeler-Westinghouse conceptual design consistent with the flexibility requirements of the test program. Boiler Drawings are OP-720-9, OP-724-82, 83 and 84.

a) Boiler Specification

The boiler is designed to operate at: gas side pressure up to 20 atm.; bed temperature 1300-2000oF; gas velocity 6 to 15 feet per second; bed depth 10 feet to 30 feet; bed plan area 35 square feet; three heat exchange bundles capable of handling bed heat exchange duties of 85.7×10^6 Btu's/hr, 149.6×10^6 Btu's/hr and 222.6×10^6 Btu's/hr at 1600°F.

- Each bundle would be capable of operating as an economizer or preheater, an evaporator and a superheater. Furthermore the bundles would be capable of operating at reduced mass flows as a combined evaporator and superheater connected in series with the water walls. In the latter case, water at 20°F. below saturation would be fed to the water walls and leave the bundles as superheated steam at 1000°F.
- The water walls would be capable of operating as a water-cooled heat exchanger or an evaporator generating saturated steam.

IV. Detailed Boiler Design (continued)

1. Boiler Design (continued)

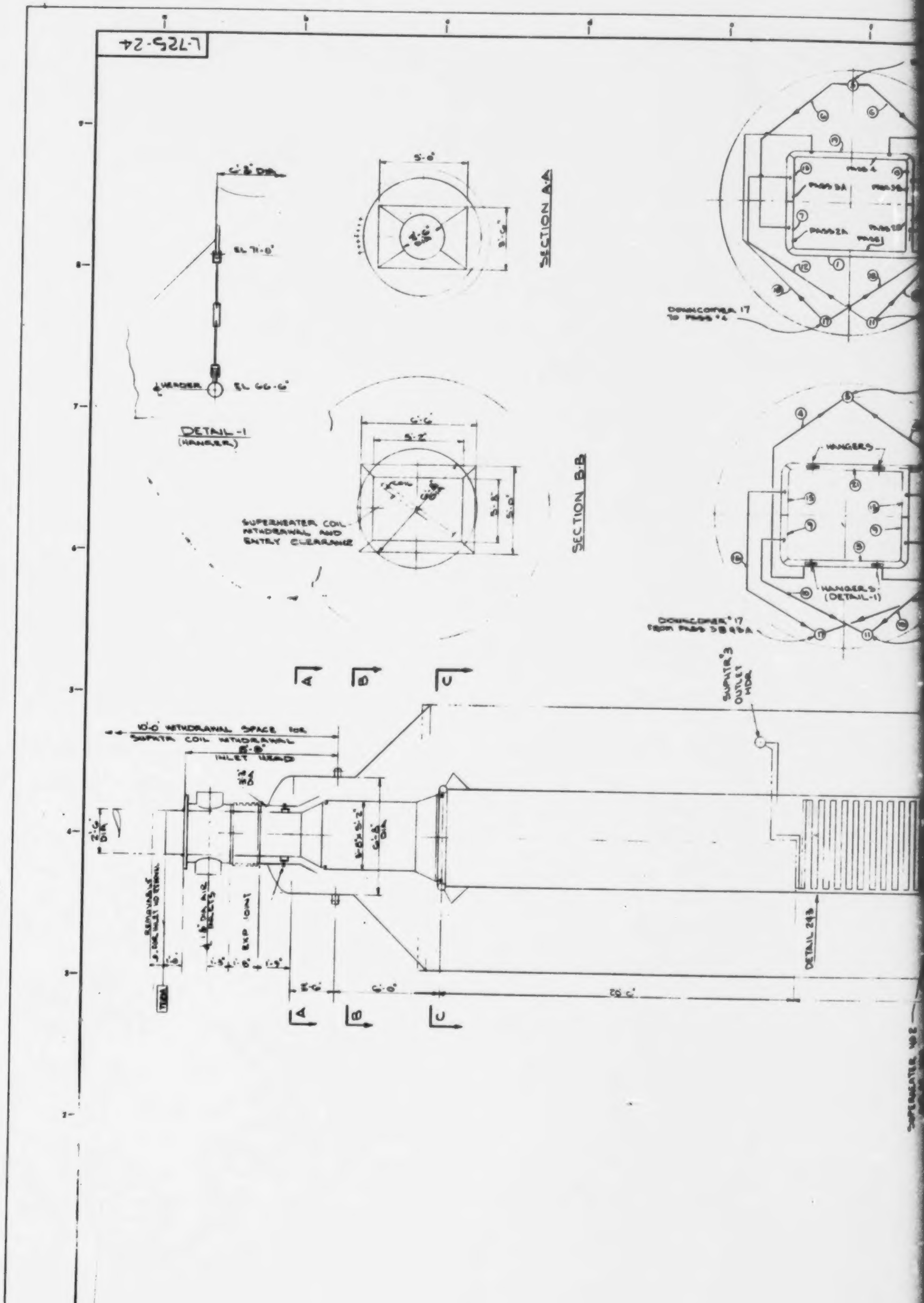
a) Boiler Specification (continued)

- The steam generator would be designed such that the three different heat transfer surfaces submerged in the bed could be interchanged with minimum cost and effort.
- The boiler would be designed such that each bundle could be installed or withdrawn as a single unit.
- The air distributor grid could be relocated at three different elevations.
- A variable freeboard height above the bed would be provided with a maximum of 20 feet for disengagement of particles splashed up from the bed.
- An overall heat transfer coefficient of 50 Btu/hr ft^2 °F would be used to determine surface requirements.
- The boiler would be installed in one of a variety of sites.

Two designs were proposed to meet these requirements. The first design, shown in Figure IV-A, contained three separate bundles stacked one above the other with three feet of crawlspace between bundles, permitting access for maintenance. Headers were located in the preheated air zone where temperatures were low and operating conditions less severe. Either individual coils or platens or the entire bundle can be pulled to fulfill changes in test requirements or make repairs.

The second design shown in Figures IVB-1 through 4 supported from headers located in the high temperature gas passes reducing the number of connections that must be broken or made for removal or installation of the bundle.

A



L-725-24
SECTION A-A
5'-0"
SECTION B-B
6'-6"
5'-2"
5'-0"
DETAIL-1
(HANGER)
EL 71-0'
HEADER
EL 66-6'
SUPERHEATER COIL WITHDRAWAL AND ENTRY CLEARANCE
DOWNCOMER 17 TO PASS 4
PASS 3A
PASS 2A
HANGERS
HANGERS (DETAIL-1)
DOWNCOMER 17 FROM PASS 3B & 3A
SUPHTR 3 OUTLET HDR
A
B
C
10'-0" WITHDRAWAL SPACE FOR SUPHTR COIL WITHDRAWAL
8'-8"
INLET HEAD
2'-0" DIA
6'-8" DIA
REMOVABLE
EXP JOINT
DETAIL 2&3
5'-0"
6'-0"
20'-0"
SUPERHEATER

B

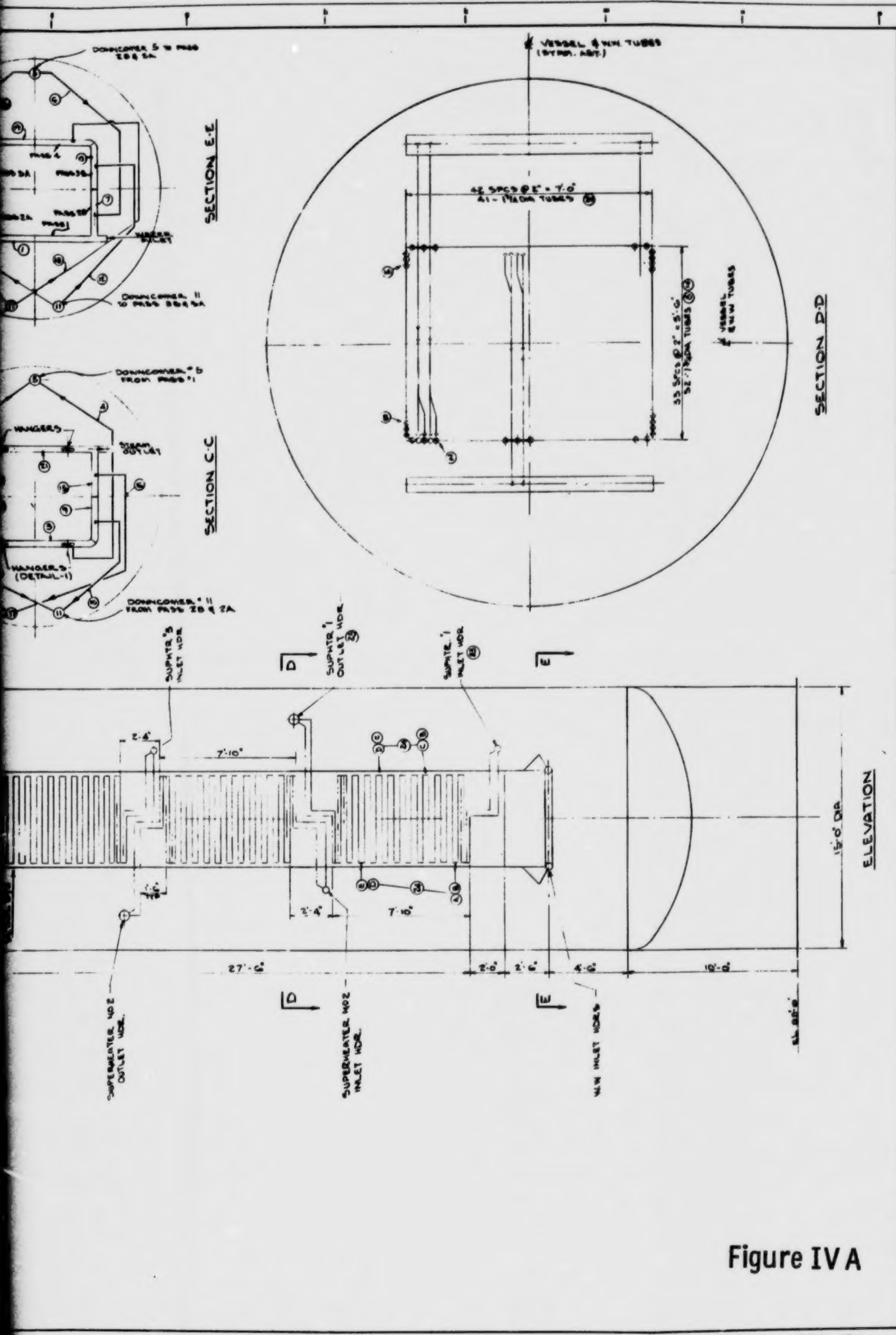


Figure IV A

NOTES

1. DO NOT SCALE THIS DRAWING. USE FIGURED DIMENSIONS ONLY.
2. ABBREVIATIONS USED ON THIS DRAWING ARE IN ACCORDANCE WITH AMERICAN STANDARD "ABBREVIATIONS FOR USE ON DRAWINGS."

ITEM	DESCRIPTION	REQD (PER ITEM)
1-7-13&19	INLET HEADER - 1 REQD 4" PIPE SCH.XX SA-106C	
2	WATER WALL TUBES - 41 REQD 1¾ OD x .165 MW SA-210A	
3	W.W OUTLET HEADERS - 1 REQD 4" PIPE SCH. XX SA-106C	
5-11&17	DOWNCOMER - 3 REQD 6" NOMINAL SCH 120 SA-106C	
6-12&18	FEEDERS - 2 REQD 2½ OD x .200 MW SA-210A	
4-10&16	TRANSFER PIPE - 2 REQD 2½ OD x .200 MW SA-210C	
8&14	WATER WALL TUBES - 32 REQD 1¾ OD x .165 MW SA-210C	
20	WATER WALL TUBES - 41 REQD 1¾ OD x .165 MW SA-210A	
22	PASS #4 TRANSFER PIPE 1 REQD 4" PIPE SCH XX SA-106C	
9-15&21	WW OUTLET HEADERS - 1 REQD 4" PIPE SCH XX SA-106C	
23	SUPERHEATER #1 INLET HDR. 1 REQD 6" NOM. SCH 160 SA-106C	
24A	SUPHTR #1 TUBES - 40 REQD 1½ OD x .225 MW SA-210A	
24B	SUPHTR #1 TUBES - 40 REQD 1.5 OD x .192 MW SA-213-T2	
24C	SUPHTR #1 TUBES - 40 REQD 1.5 OD x .175 MW SA-213-T11	
24D	SUPHTR #1 TUBES - 40 REQD 1.5 OD x .380 MW SA-213-T22	
24E	SUPHTR #1 TUBES - 40 REQD 1.5 OD x .282 MW SA-213 TP304H	
25	SUPHTR #1 OUTLET HD. - 1 REQD 6" NOM x 1.28 AW SA-335-P22	
*	THE SUPHTRS #2 & 3 THE SAME PRESSURE PARTS ARE REQD AS FOR SUPHTR #1	

PRELIMINARY 8/28/72

LETTER	DATE	BY	DESCRIPTION

REVISIONS

PRESSURIZED
FLUID BED
TEST BOILER
SECTIONS & DETAILS

DRAWING NUMBER — SCALE 1/8 & 1/4 = 1'-0"

L-725-24

DWG. MADE & APPROVED BY	INITIAL	DATE	CUST. NO. 3-59-351
DRAFTSMAN	JM		
CHECKER			
SQUAD LEADER			
SECTION HEAD			
CHIEF ENGR.			

This Drawing is the Property of the
FOSTER WHEELER CORPORATION
110 So. Orange Ave. Livingston, N.J.

THIS DRAWING SUPERSEDES
THIS DRAWING SUPERSEDED BY

DWG. NO. L-725-24

2/7 34%

IV. Detailed Boiler Design (continued)

1. Boiler Design (continued)

The first design has the advantage of utilizing only that coil surface area required for either cases A-1, A-2 or A-3 operation. The second design always has two spare bundles since each of the bundles is adequate for its own operating capacity. However, the first design has the disadvantage of requiring many cutting and welding operations on each tube to make any changes in tube bundles, adding time and money to any change. The first design also has the disadvantage of using crawlspaces between bundles which would not be designed into the commercial units. These crawlspaces may upset the fluidization hydraulics leading to difficulties in scaling-up from the demonstration to the commercial unit. The second design was chosen as superior in flexibility and in fluidized bed hydraulics.

b) Construction

The steam generator was designed to operate on feed water from an existing 2400 psig once-through system with a final steam temperature of 1000°F. These conditions are considered to be representative of existing power plants.

The heat transfer surface inserted in the bed consists of one of three separate but continuous bundles of horizontal serpentine tubes. The surface requirements of each bundle were selected to meet the bed duties specified with due consideration given to the duty of the enclosure wall. The smallest bundle consists of forty rows of single loop-in-loop, 1½" O.D. tubes with alternate rows off-set vertically (see Drawing OP-724-84, Fig. IVB-2) providing a triangular pitch with tube spacing of 2.828 inches. Larger bundles make use of the same tube arrangement and tube size. However, double loop-in-loop and

IV. Detailed Boiler Design (continued)

1. Boiler Design (continued)

b) Construction (continued)

triple loop-in-loop construction is used to accommodate higher steam mass flows at the higher bed duties with nearly constant steam side pressure drop. The schedule of tube material and wall thickness appears in Table VII. The latter was selected on the basis of superheating in the bundle and should be equally satisfactory for evaporating and preheating functions providing demineralized water from an existing once-through installation is used and no chlorides are present.

The bundles are constructed with one inlet header and two outlet headers operating in parallel. That is to say alternate tubes feed to alternate headers. This was done so as to support the bundle from the headers located within the gas stream. Continuous bundles in beds 15 to 27 feet deep are too heavy to be supported off lugs attached to the water wall. Individual loops are held together with a sinuous strap made of an alloy steel running the full length of the bundle. The sinuous straps are tied to the supporting headers. In addition to supporting individual coils and preventing them from arbitrarily expanding of their own weight, the sinuous straps make the bundle rigid and reduce the stress on the tubes at the first tube bend created by the bending moment of the cantilevered bundle.

Two headers are used in series at the outlet to facilitate support during operation and simplify removal during modification. The first is essentially a collecting header for the tubes in the bundle. The second header is a steam-cooled beam supporting the bundle and providing access to either end for cutting during removal. The two headers are connected with four transfer pipes forming a truss capable

IV. Detailed Boiler Design (continued)

1. Boiler Design (continued)

b) Construction (continued)

of discharging steam from the bundle. The supporting header requires a cylindrical insert to form an internal annulus so as to maintain high steam velocities, good heat transfer and low mean wall header temperature. The two supporting headers penetrate the water walls at four locations. The four steam outlet pipes are collected or manifolded into a single discharge line outside the boiler. By connecting two outlet headers with a series of transfer pipes judiciously located along the length of the header, sufficient room is provided at either end of the supporting header to cut the header at the time of removal. Two cuts must be made at either end, one on either side of the water wall. The spool section thus formed is removed to provide sufficient room for pulling the bundle. Re-welding of the header requires stress retrieving and X-raying the welds.

The same outlet and inlet header connections will be used for all three bundles. The difference in elevation of the outlet headers for the smaller bundles is absorbed by longer transfer pipes between the collecting and supporting header.

The fluid bed is enclosed with a monofin membrane wall capable of withstanding 12 psi pressure differential (maximum expected with a 30' bed) between the preheated air and the products of combustion. The water wall enclosure serves as a heat transfer surface, a partition between the preheated air and flue gas, and means of structurally supporting the pressure parts. It also acts as insulation providing a means for designing the shell for high pressure low temperature operation.

IV. Detailed Boiler Design (continued)

1. Boiler Design (continued)

b) Construction (continued)

The water wall enclosure can be penetrated rather simply. This permits locating larger, more expensive piping not serving as heat transfer surface in cooler gas zones outside of the enclosure surface where the environmental conditions are less severe. Locations of water wall penetrations can be changed in the field by simply cutting out the section of offset tubing and replacing it with a section of straight tubing, or vice versa.

The water walls also provide a simple means of support with appropriate consideration given to load and local stress concentrations.

The favorable characteristics of the membrane wall already cited demonstrate some of the advantages of this type of construction. On the other hand, refractory-lined plate steel greatly complicates tube support. Maintenance will be high, particularly with severe thermal cycling associated with a test vehicle. The wall areas in the immediate vicinity of the tube bundles are inaccessible. Refractory could be particularly troublesome if large pieces breaking loose from the wall become entrained in the exit flue gases.

A rough cost estimate indicated one square foot of reinforced monofin wall might run $12 per square foot. A refractory wall, constructed of ½ inch plate with 4 inches of refractory and 2 inches of insulation, would cost approximately $24 per square foot. About 20% additional surface would have to be added to the bundle immersed in the bed to compensate for the loss in heat transfer to the wall.

The load-supporting water wall is constructed of 1-7/8 O.D. inch tubes on 2 inch centers. The remaining two walls are constructed of

IV. Detailed Boiler Design (continued)

1. Boiler Design (continued)

b) Construction (continued)

1-3/7 O.D. inch tubes on 2 inch centers. Tube thickness and material selection appear in Table VII. The water walls are reinforced with 10 WF tie bars on variable centers. As the pressure differential across the wall increases the center lines between adjacent tie backs decreases.

Each wall is terminated at both ends by a header. The headers are partitioned such that the water wall circuit may be operated as a single-pass or four-pass heat exchanger in four walls connected in series rather than parallel. Modifying the water walls from single-pass to four-pass is achieved by cutting loose the second ring header at the transfer pipes and sealing the latter. The single inlet pipe to the primary header then is connected to the feed line. A similar modification is required at the discharge end.

The bundles and enclosure walls are hung from the shell at the uppermost extremity. Since the shell water walls and preheated air are at about the same temperature, expansion problems are minimized.

All water/steam pressure parts were designed according to Section I of the American Society of Mechanical Engineers Power Code.

The shell is a self-supporting vessel approximately 78 feet high, designed according to Section VIII UG27 Un-fired Pressure Vessel American Society of Mechanical Engineers Power Code for pressures of 320 psig at temperatures of 500°F. The vessel is constructed of 1-3/8 in. thick SA 516-70 steel and lined with a 2-inch layer of batten insulation with an 0.04"aluminum sheathing. The shell is 12 feet in diameter. The size was selected as the maximum diameter permissible for shipment

IV. Detailed Boiler Design (continued)

1. Boiler Design (continued)

b) Construction (continued)

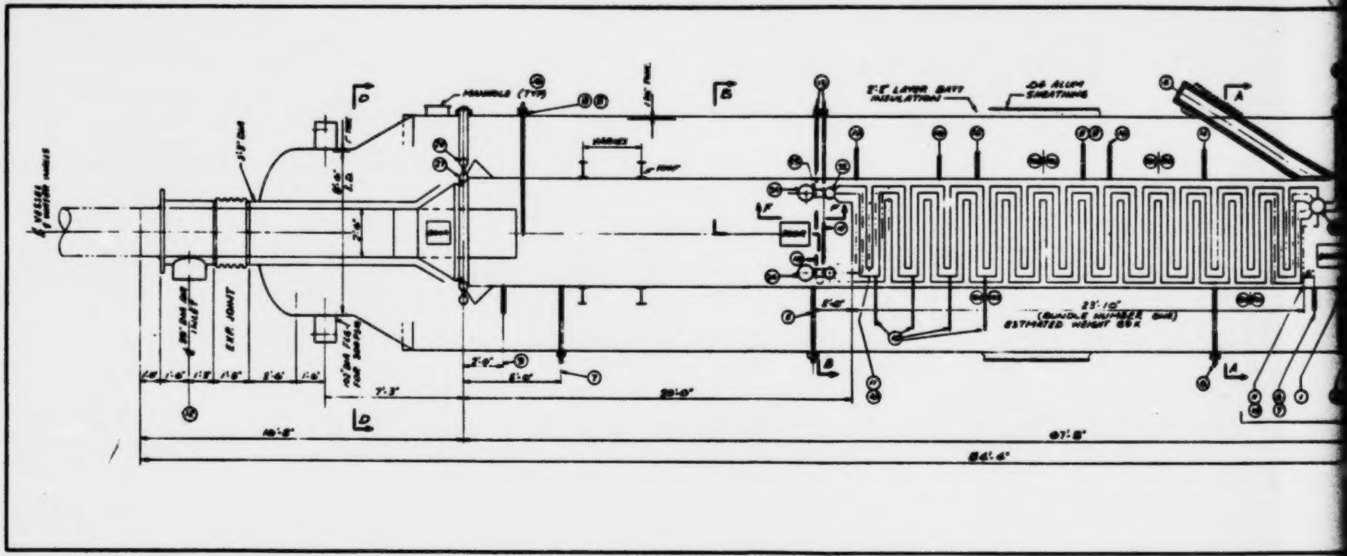
as a complete shop-fabricated and assembled unit and minimum diameter for internal access to the water-steam pressure parts.

The upper section of the vessel is reduced to 8 feet 6 inches internal diameter by a conical transition piece to permit installation of a removable head by means of a flange connection.

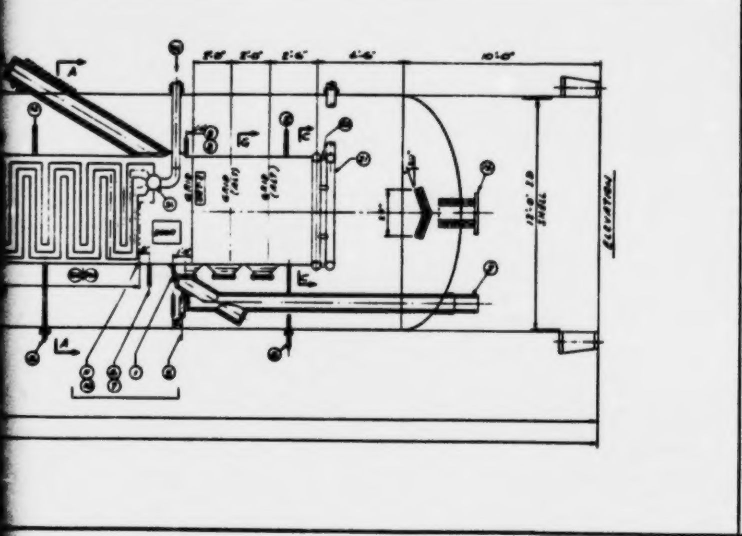
Preheated air is introduced and flue gas withdrawn through an air-cooled pipe penetrating the upper-dished head closing off the top of the vessel. The air-cooled piping penetrates the vessel approximately five feet. A transition piece is attached to its furthermost extremity completing a sealed connection to the uppermost point of the water walls. A mechanical seal completes the connection. When broken, it provides access to the entire fluid bed and immersed heat exchanger bundle. This permits removal of the bundle as a single unit.

The air distributor, shown in Fig. IVB-3, consists of three sections of Wrought Incoloy 800 plate, supported by scalloped bars welded to the water walls and completely circumscribing the bed. The air distributor is held in position by wedges inserted between inverted water wall hanger supports and the grid plate. The air distributor contains 598 bull plugs, each containing 16, 0.2 inch diameter holes for emitting and distributing air to the fluid bed. The three sections of air distributor are bolted together at the web located in the plenum chamber. This arrangement makes it possible to remove the air distributor and relocate it at any one of three elevations.

A


MANHOLE (TYP)
2'-8" LAYER BATT INSULATION
.04 ALUM SHEATHING
VARIES
EXP. JOINT
2'-6"
1'-6"
1'-8"
1'-6"
3'-6"
1'-6"
7'-3"
2'-0"
6'-0"
20'-0"
16'-8"
67'-8"
84'-4"
23'-10"
(BUNDLE NUMBER ONE)
ESTIMATED WEIGHT 65K
A
B
D
F
7

B



ITEM	DESCRIPTION	REQ'D PER ITEM NO.
21/22	INLET HEADER 6" PIPE SCH XX SA-106C	1-REQ'D
23/24	WATER WALL TUBES 1½" OD × .220 MW SA-210A	43-REQ'D
25/26	WATER WALL TUBES 1½" OD × .220 MW SA-210A	33-REQ'D
27/28	WW OUTLET HEADERS 6 PIPE SCH XX SA-106C	1-REQ'D
29/30	TRANSFER PIPE 3½ OD × .280 MW SA-210A	6-REQ'D
31	BUNDLE #1 INLET HEADER 8" PIPE SCH 160 SA-106C	1-REQ'D
32	BUNDLE #1 OUTLET HEADER 6 OD × 1.10 MW SA 335 - TP 304H	2-REQ'D
33A	BUNDLE #1 TUBES 1½ OD × .225 MW SA-210A	110-REQ'D
33B	BUNDLE #1 TUBES 1½ OD × .192 MW SA-213-T2	120-REQ'D
33C	BUNDLE #1 1½ OD × .275 MW SA-213-T2	120-REQ'D
33D	BUNDLE #1 TUBES 1½ OD × .380 MW SA-213-T22	120-REQ'D
33E	BUNDLE #1 TUBES 1½ OD × .338 MW SA-213 TP304H	120-REQ'D
*	FOR BUNDLES 2 & 3 THE SAME MATERIAL CHANGES ARE REQ'D AS FOR SUPERHEATER #1	
34	BUNDLE OUTLET HEADER 8⅝" OD × 1½ MW SA-335-TP 304H	1-REQ'D
35	OUTLET PIPE 3½ PIPE .400 MWL SA-335-TP 304-H	6-REQ'D
36	BUNDLE #2 INLET HEADER 8 PIPE SCH 160 SA-106 C	1-REQ'D
37	BUNDLE #2 OUTLET HEADER 6" PIPE SCH XX SA-335 TP 304H	2-REQ'D
38	BUNDLE #3 INLET HEADER 6" PIPE SCH 160 SA-106-C	1-REQ'D
39	BUNDLE #3 OUTLET HEADER 6" PIPE SCH XX SA-335 TP 304 H	2-REQ'D

DESIGN NOTES

1. WATER/STEAM PRESSURE PARTES ARE DESIGNED TO SECTION I OF POWER CODE.
2. SHELL DESIGNED TO SECTION VIII UG 27 UNFIRED.
3. SHELL 320 PSIG @ 500°F
4. WATER WALLS TEMP 700°F AND PRESS 2700 PSIG
5. SUPERHEATER TEMP 1000°F FST @ 2700 PSIG
6. WATER WALLS 15 PSI DIFFERENTIAL BETWEEN FLUID BED AND SHELL

GENERAL NOTES

1. DO NOT SCALE THIS DRAWING. USE FIGURE DIMENSIONS ONLY.
2. ABBREVIATIONS USED ON THIS DRAWING ARE IN ACCORDANCE WITH AMERICAN STANDARD "ABBREVIATIONS FOR USE ON DRAWINGS."
3. ALL NOZZLES LISTED IN NOZZLE CHART, WW INLET AND OUTLET CONNECTIONS AND SUPERHEATER INLET AND OUTLET CONNECTIONS TO HAVE BELLOWS SEALS AT PENETRATIONS OF VESSEL SHELL.

NOZZLE CHART

NO	I.D.	NOM SIZE	SERVICE	NO. REQ'D
1		1	COAL/DOLOMITE INJECTION	6
2	8	20	DOLOMITE WITHDRAWAL	1
3		2	DOLOMITE INJECTION	3
4	8	20	FINES RETURN	1
5		4	IGNITION NOZZLE	2
6		1	PDR	2
7		1	PDRC	2
8		1½	TI, TR	7
9		1½	TSH, TAH	1
10		SPECIAL	TI, TR (FLUID)	75
11		SPECIAL	TI, TR (SKIN)	6
12		20	AIR INLET	1
13		1½	TEST LOOP	2
14		1	SAMPLE CONNECTION	3
15	18	30	HEATER H-103 NOZZLE	1
16	18	30	MANWAY	6

LEGEND

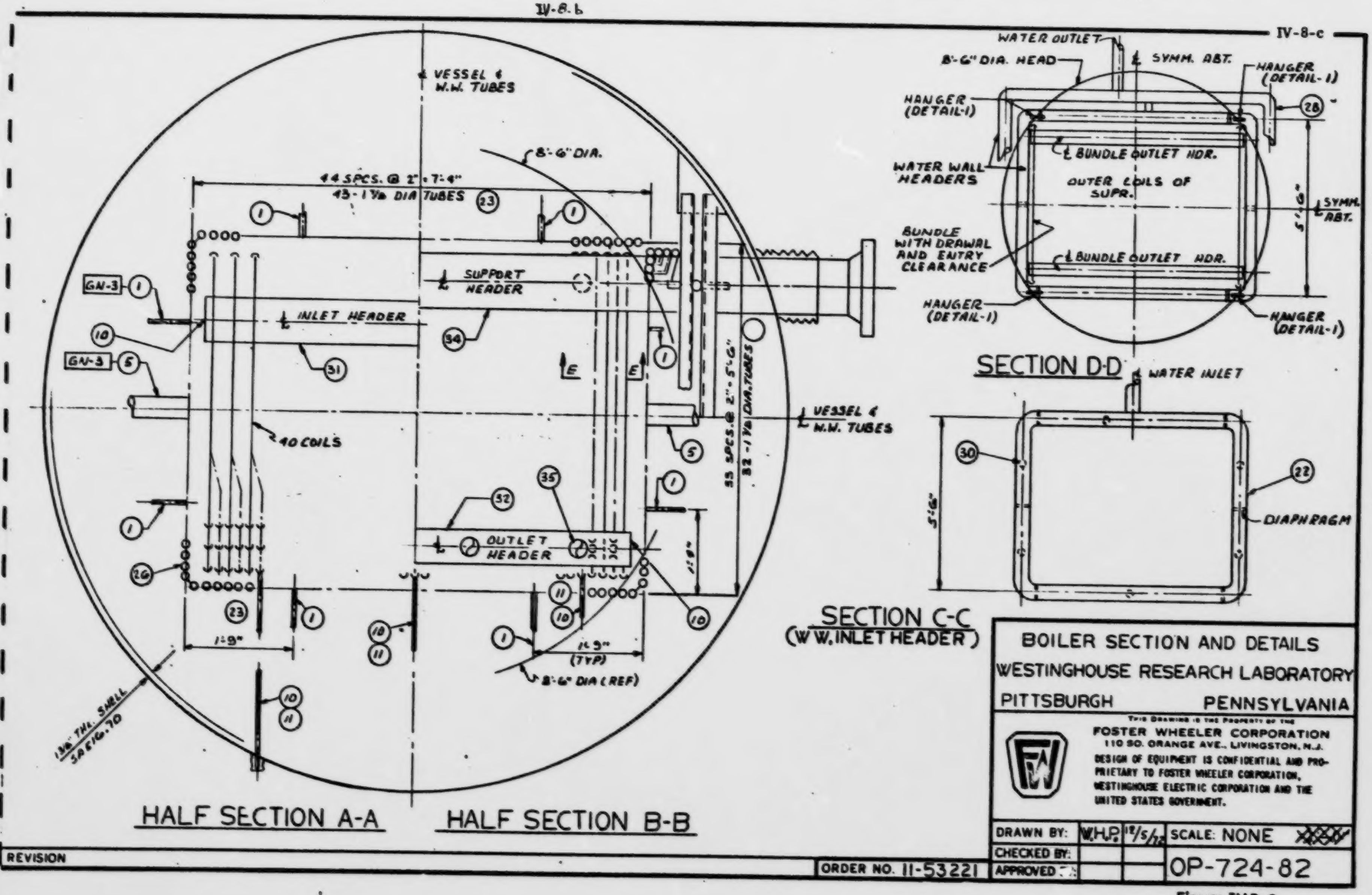
TI	TEMPERATURE INDICATOR
TR	TEMPERATURE RECORDER
PDR	PRESS DIFFERENTIAL RECORDER
PDRC	PRESS DIFF RECORDER CONTROLLER
TSH	TEMPERATURE SWITCH HIGH
TAH	TEMPERATURE ALARM HIGH

Figure IV8-1

This Drawing is the Property of the
Foster Wheeler Corporation
[illegible]

PRESSURIZED FLUIDIZED
BED BOILER
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PENNSYLVANIA

11-52335
DWG. NO. OP-720-9



BOILER SECTION AND DETAILS
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PENNSYLVANIA

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CHECKED BY:			OP-724-82
APPROVED:			

Figure IV B-2

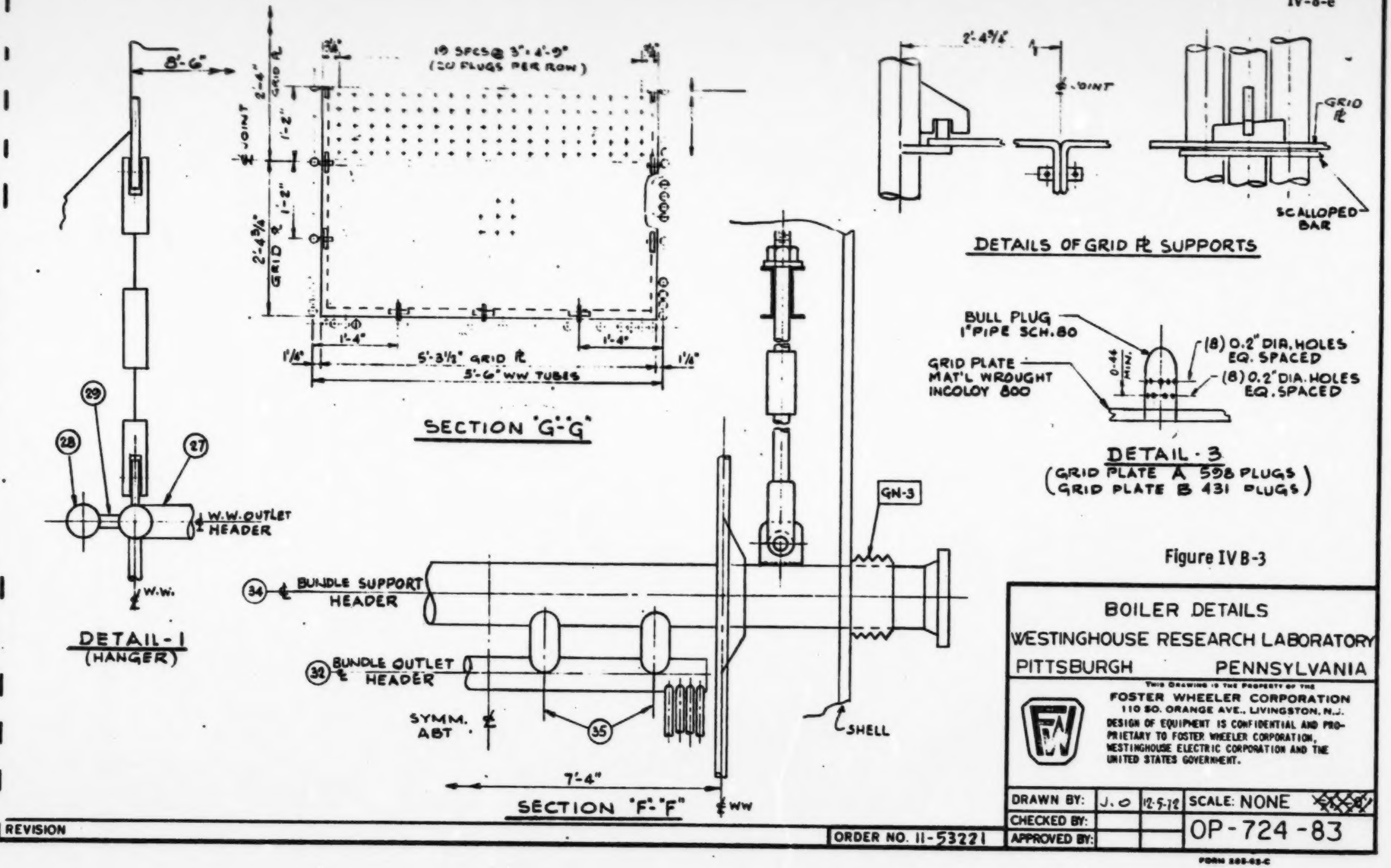

Figure IV B-3

BOILER DETAILS
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DRAWN BY:	J. O	12-5-72	SCALE: NONE
CHECKED BY:			OP-724-83
APPROVED BY:			

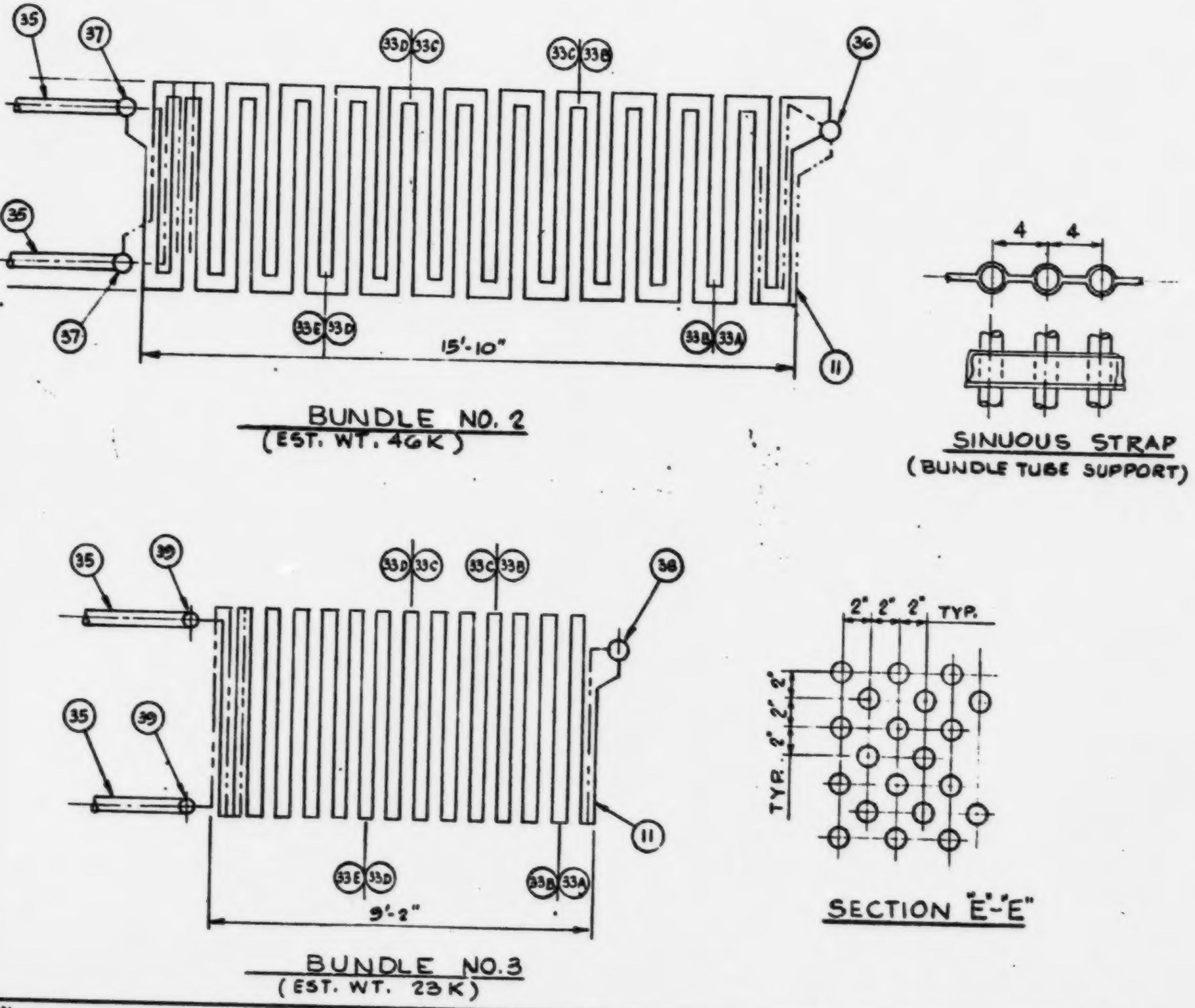
ORDER NO. 11-53221

FORM 303-03-C

IV.8.F

IV-8-g

TOTAL METAL WEIGHT (LESS BUNDLE)	= 282 K
INSULATION & LAGGING	= 20 K
BUNDLE NO. 1	= 69 K
BUNDLE NO. 2	= 46 K
BUNDLE NO. 3	= 23 K



BUNDLE NO. 2
(EST. WT. 46K)

SINUOUS STRAP
(BUNDLE TUBE SUPPORT)

BUNDLE NO. 3
(EST. WT. 23K)

SECTION "E"-"E"

Figure IV B-4

BUNDLE DETAILS
WESTINGHOUSE RESEARCH LABORATORY
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CHECKED BY:			OP-724-84
APPROVED BY:			

REVISION

ORDER NO. 11-53221

FORM 503-63-C

IV. Detailed Boiler Design (continued)

1. Boiler Design (continued)

c) Maintenance

Access to the fluid bed is achieved through either the removable head for major repairs or manways in the pressure vessel and water walls for minor repairs. The manways are located above and below the bed and in the transition piece at the flue gas exit.

The bundles may be removed and interchanged by unbolting the flanged head and mechanical seal between the air-gas duct and water wall headers. The section comes off as a single unit. The supporting outlet headers must be cut at four locations on either side of the water wall enclosure. The lower inlet header must also be cut on both sides of the water wall. After the bundle is raised slightly the spool sections formed by the two cuts can be removed. After this the bundle is free to be pulled as a single unit.

Repair of individual tubes requires pulling the entire bundle. This is one of the disadvantages of locating the headers inside of the water wall enclosure. In the original design, individual coils or platens can be pulled up into the freeboard area and repaired without having to remove the pressure vessel head.

Installation of the bundle requires stress relieving and X-raying of the header welds.

IV. Detailed Boiler Design (continued)

1. Boiler Design (continued)

d) Operation

All three bundles can be operated as either a superheater, evaporator or preheater providing proper consideration has been given to the relationship between bed duty, waterside mass flows, inlet enthalpy and pressure drop. The cooling fluid must be de-mineralized water, free of chlorides to prevent stress corrosion on the stainless steel segments of the bundle. The heat flux to the tubes is low according to the design conditions specified, 30,000-60,000 Btu/hr ft^2. Therefore, overheating of the tube surface in the evaporation mode of the transition from wet steam to dry should not present a problem. Figure V illustrates a typical relationship between tube metal temperature, heat flux, enthalpy and steam quality.

By dropping the mass flow, the bundles can be operated as a combined evaporator and superheater.

The water walls can be operated as a single water-cooled heat transfer bundle in either the single-pass or multi-pass arrangement. The water walls can also be operated as a verticle tube evaporator.

By selecting the appropriate mass flows and making necessary changes in the circuitry piping the water walls can be connected in series with the immersed bundle such that the boiler can be operated as a once-through boiler with 20^{o}F. of sub-cooling at the feed inlet and 1000^{o}F. at the superheater outlet.

All of these operating modes are subject to restrictions of the system pressures, temperatures and operating conditions. These cannot be taken into consideration until a site is selected and specific system piping is established. The boiler was designed to operate on a slip-

IV. Detailed Boiler Design (continued)

1. Boiler Design (continued)

d) Operation (continued)

stream from a once-through boiler at 2400 psig. The feed water would most likely come from the economizer outlet. The saturated steam may be produced as superheated steam that has been de-superheated to saturation. Unless a very special boiler is selected with adequate temperature control, slipstreams of the size required cannot be taken from the boiler at locations between the economizer and superheater outlet.

Table VIII is a schedule of pressure drop for the various modes of operation requested in the final design. These will have to be modified to the system requirements by changing header sizes, tube sizes, number of tubes or other physical modifications that may be found necesaary.

TABLE VII

BOILER TUBE MATERIAL

ITEM	DESCRIPTION	SIZE	MATERIAL	NUMBER REQUIRED
21 & 22	Inlet Header	4" Pipe SCHXX	SA-106C	1
23 & 24	Water Wall Tubes	1 7/8 OD x·220 MW	SA-210A	43
25 & 26	Water Wall Tubes	1 7/8 OD x·220 MW	SA-210A	32
27 & 28	W/W Outlet Headers	6"Pipe SCHXX	SA-106C	1
29 & 30	Transfer Pipe	2 1/2"OD x·200 MW	SA-210A	6
31	Superheater #1 Inlet Header	8" Pipe SCH 160	SA-106C	1
32	Superheater #1 Outlet Header	6"Nom x 1.28 AW	SA-335-TP304H	2
33 A	Superheater #1 Tubes	1 1/2"OD x .225 MW	SA-210A	120
33 B	Superheater #1 Tubes	1 1/2"OD x .192 MW	SA-213-T2	120
33 C	Superheater #1 Tubes	1 1/2"OD x .375 MW	SA-213-T11	120
33 D	Superheater #1 Tubes	1 1/2"OD x .385 MW	SA-213-T22	120
33 E	Superheater #1 Tubes	1 1/2"OD x .232 MW	SA-213-T304H	120
34	Superheater Support Header	8 5/8"OD x 1 1/2 AW	SA-335-TP304H	2
35	Outlet Pipe	3 1/2"Pipe .469 Wall	SA-335-TP304H	8
36	Superheater #2 Inlet Header	5"Pipe SCH 160	SA-106-C	1
37	Superheater #2 Outlet Header	4" Pipe SCHXX	SA-335-TP304H	2
38	Superheater #3 Inlet Header	4" Pipe SCH 160	SA-106-C	1
39	Superheater #3 Outlet Header	4" Pipe SCHXX	SA-335-TP304H	2

(1) Numbers refer to items illustrated in Drawing L-725-32, Figure 1.

(2) Superheaters 2 & 3 require the same material as Superheater 1.

(3) Superheater 2 requires 2/3 the number of tubes in Superheater 1, Superheater 3 requires 1/3 the number of tubes in Superheater 1.

(4) SA material specifications may be found in Section II, Materials Specifications of the ASME Boiler and Pressure Vessel Code.

TABLE VIII
SUMMARY
OF
PRESSURE DROP CALCULATIONS

CASE	A-1	A-2	A-3
Bed Duty BTU/HR x 10^6	149.6	85.7	227.6
Bundle Duty	98.3	55.1	146.1
Wall Duty	51.3	30.6	76.5

Superheater Outlet Temperature 1000°F
Superheater Outlet Pressure 2400 PSIG
U = 50 BTU/HR F^2 °F

MATERIAL	SELECTION	O.D.	I.D.	TUBE A_c*	ϵ *	LENGTH
Water Walls SA 106C	(1 Pass)	1 7/8	1.435	1.670	0.0018	53
Headers	SA-106C	4.5	3.152	7.80	------	----
Bundle						
Sec. 1	SA-210 A	1 1/2	1.024	.824	0.0018	129, 150, 127
Sec. 2	SA-213-T2	1 1/2	1.100	.950	0.001	17, 17, 17
Sec. 3	SA-213-T11	1 1/2	.750	.442	0.001	27, 27, 27
Sec. 4	SA-213-T22	1 1/2	1.700	.385	0.0005	32, 32, 32
Sec. 5	SA-213-TP304	1 1/2	1.024	.824	0.00006	16, 16, 16
Headers	SA-106C	6.625	5.5	23.6		35, 59, 35

CASES STUDIED

(1) Bundle 1, 2, 3 as a superheater. Sat. steam in. 1000°F Supht. out at 2400 psig.

(2) Bundle 1, 2,3 as an evaporator. Sat. water in. Sat. steam out at 2400 psig.

(3) Bundle 1, 2,3 as a preheater.Subcooled water in. 212°F inlet temp., 2400 psig.

(4) Water walls as a preheater subcooled water 212°F inlet temp., 2400 psig press. - Single and four pass arrangement.

(5) Water walls as an evaporator 20°F subcooled water in at 2400 psig press. and saturated vapor out - Single and four pass arrangement

(6) Complete once through system. 20° preheater to water walls. 1000°F superheat from bundle.-Single and four pass arrangement of water walls.

*Nomenclature appears at the end of Table VIII.

TABLE VIII (continued)

SUMMARY
OF
PRESSURE DROP CALCULATIONS
(Continued)

CASE 1, 2, 3 PRESSURE DROP THROUGH BUNDLE

BUNDLE INSTALLED	A-1	A-2	A-3
Mode of Operation		Superheat	
ΔP_f PSI	94.9	130.1	98.4
$W \times 10^3$ Lb/Hr	255	143	380
$W/A \times 10^3$ Lb/Hr - Ft^2 (Inlet)	545	614	540
Mode of Operation		Evaporator	
ΔP_f PSI	41.9	51.7	43.6
ΔP_h	2.6	1.9	4.0
ΔP_t	44.5	53.6	47.6
$W \times 10^3$ Lb/Hr	260	147	390
$W/A \times 10^3$ Lb/Hr - Ft^2 (Inlet)	556	625	561
Mode of Operation		Preheater	
ΔP_f PSI	11.4	14.7	11.4
ΔP_h	4.3	2.9	6.6
ΔP_t	15.7	17.6	18.0
$W \times 10^3$ Lb/Hr	250	150	384
$W/A \times 10^3$ Lb/Hr - Ft^2 (Inlet)	534	650	560
ΔT_w	390	390	390

CASE 4 WATER WALL AS A PREHEATER

BUNDLE INSTALLED	1	2	3
Single Pass			
ΔP_f PSI	1.22	0.43	2.81
ΔP_h	14.1	14.1	14.1
ΔP_t	15.3	14.5	16.9
$W \times 10^3$ Lb/Hr	250	150	384
$W \times 10^3$ Lb/Hr - Ft^2 (Ave.W.W.)	148	89	228
ΔT_w	206	206	206
Four Passes			
ΔP_f PSI	58.5	21.1	134.2
ΔP_h	14.1	14.1	14.1
ΔP_t	72.6	35.2	148.3
$W \times 10^3$ Lb/Hr	250	150	384
$W \times 10^3$ Lb/Hr - Ft^2 (Ave. W.W.)	525	316	810
ΔT_w	206	206	206

TABLE VIII (continued)

SUMMARY
OF
PRESSURE DROP CALCULATIONS
(Continued)

CASE 5 WATER WALLS AS AN EVAPORATOR

BUNDLE INSTALLED	A-1	A-2	A-3
Single Pass			
ΔP_f PSI	2.7	2.0	5.42
ΔP_h	8.4	8.4	8.4
ΔP_t	11.1	10.4	13.82
W x 10^3 Lb/Hr	133	81	205
W x 10^3 Lb/Hr - Ft^2 (Ave. W.W.)	103	60	157
Four Passes			
ΔP_f PSI	66.1	24.5	150.0
ΔP_h	10.0	10.0	10.0
ΔP_t	76.1	34.5	160.0
W x 10^3 Lb/Hr	133	81	205
W x 10^3 Lb/Hr - Ft^2 x 10 (Ave. W.W.)	290	170	440

CASE 6 ONCE THROUGH SYSTEM

BUNDLE INSTALLED	1	2	3
Single Pass			
ΔP_f PSI	81.9	97.2	83.0
ΔP_h	8.4	8.4	8.4
ΔP_t	90.3	105.6	91.4
W x 10^3 Lb/Hr	203	115	300
W x 10^3 Lb/Hr - Ft^2 (Ave.W.W.)	122	70	182
W x 10^3 Lb/Hr - Ft^2 (Bundle-Inlet)	435	490	413
Four Passes			
ΔP_f PSI	230.1	141.6	404.6
ΔP_h	10.0	10.0	10.0
ΔP_t	240.1	151.6	414.6
W x 10^3 Lb/Hr	205	115	300
W x 10^3 Lb/Hr - Ft^2 (Ave.W.W.)	490	280	730
W x 10^3 Lb/Hr - Ft^2 (Bundle-Inlet)	435	490	423

NOMENCLATURE

ΔP	Pressure Drop	LB/SQ IN.
W	Mass Flow	LB/HR
W/A	Mass Flow Per Unit Area	LB/HR FT^2
U	Overall Heat Transfer Coefficient	BTU/HR FT^2 °F
ΔT	Temperature Difference	°F
O.D.	Outside Diameter	IN.
I.D.	Inside Diameter	IN.
A_c	CrossSectional Area	SQ.IN.
ε	Roughness	

Subscripts

f	Friction
h	Static Head
t	Total
W	Water

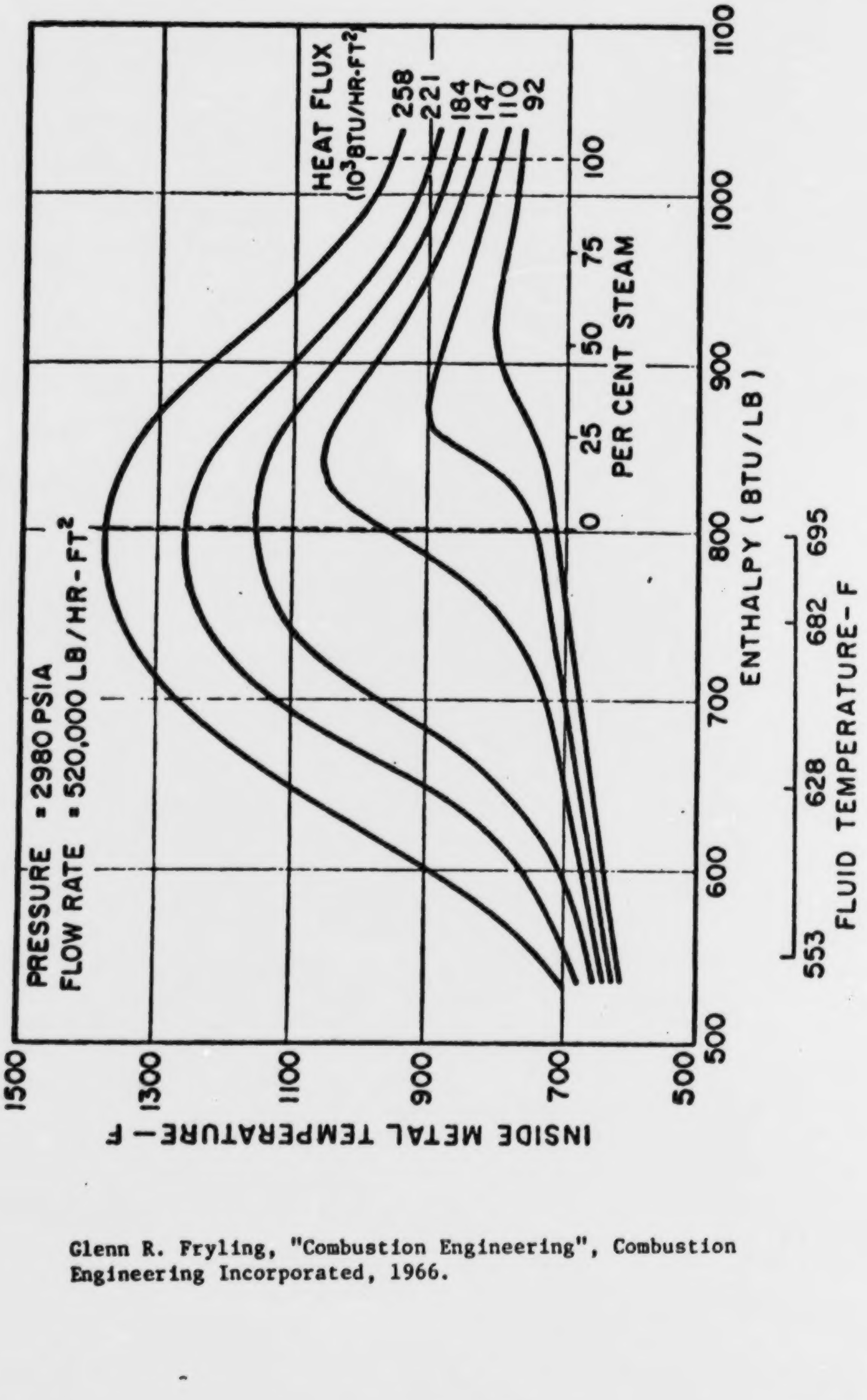

FIGURE V EFFECT OF CHANGE IN HEAT FLUX ON BURN-OUT AND DEPARTURE FROM NUCLEATE BOILING POINTS

Glenn R. Fryling, "Combustion Engineering", Combustion Engineering Incorporated, 1966.

V. Design Problems and Solutions

1. Particle Removal from Flue Gas

Gas from the combustion zone, at 1600 to 1750°F. and at pressures of from 150 to 320 psig, carries a certain amount of solid particles elutriated from the fluidized bed. These particles, consisting of fly ash, dolomite and some unburned carbon which must be removed from the gas if the high pressure energy of the flue gas is to be recovered in a turbine expander. It is vital for the process to recover as much of the pressure energy of the flue gas as possible since the compression of the combustion air consumes a large fraction of the total energy input into the boiler plant. The removal of particulates a high temperatures and pressures is not an easily solved problem. At the high temperatures electrostatic precipitators lose efficiency. Cyclones may remove much of the particulates above a certain size range, but removal efficiency tends to decrease below about 10 to 20 microns. Removal of smaller particles is slightly improved by the use of many very small cyclones, such as "Multiclones" or by the use of reverse flow cyclones such as the "Aerodyne" type. For operation of the pressurized fluidized bed boiler a first-stage cyclone removes bulk carryover of particles greater than 20 microns. These may be removed from the system or returned to the fluidized bed. The flue gases next go to an Aerodyne cyclone which removes most of the particles above 6 microns. However, if this removal is still not adequate to meet the required dust loading of 0.15 gr/SCF established by Westinghouse for the turbine, then it may be necessary to install a granular bed filter at considerably more expense than for the cyclones. A granular-bed type filter specification as proposed by Ducon for a future installation is enclosed in Appendix II.

V. Design Problems and Solutions (continued)

2. Fluidization Hydraulics

The fluidized particle consists of dolomite in the size range of ¼"x28 mesh (595 to 6350 microns). The large, average particle size may be reduced slightly by attrition; however, it will still be necessary to operate at a high gas velocity. It is felt that the smaller particles, especially unburned coal, may be elutriated out of the bed very rapidly.

High gas velocity and large particles tend to produce surgining, slugging and bumping fluidized beds.

It is felt that during the preliminary operation it will be necessary to experiment with the effect of particle size on smoothness of fluidization. Directionally, it may be necessary to reduce the top size of dolomite from ¼" to 4 or 6 mesh. The smaller, average particle size may reduce capacity by limiting gas velocity but the smaller size should improve heat transfer and smoothness of fluidization.

3. Steam and Boiler Feed Water

It has been assumed that the pressurized fluidized bed boiler will be located adjacent to an existing power plant. The experimental boiler will take saturated steam from the existing power plant and return superheated steam, or the experimental boiler will take preheated water and return saturated steam.

Since the adjacent power plant has not been specified, it has been necessary to design the experimental boiler on the basis of a series of assumptions as to steam pressure, superheat temperature and also the pressure drop through the experimental boiler. If the system pressure drop is too high it will be impossible to get steam back into the power plant's system in which case it may be necessary to break the pressure to some lower stage on the power plant's turbine interstage pressure.

V. Design Problems and Solutions (continued)

3. Steam and Boiler Feed Water (continued)

It also may be very difficult to convince a power plant to tap into the power plant's main boilers to remove saturated steam and return saturated steam to the power plant's superheaters. This could upset the firing balance of the power plant.

It may be better to operate the test facility without tapping into the power plant's boiler. Boiler feed water can be taken from the power plant's boiler feed water preheaters and exchangers and this water sent to the fluidized bed boiler water tubes for preheat and evaporation. From the water wall tubes steam and water flows to the tube bundle in the fluidized bed to complete evaporation and then to superheat to 1000°F. The high pressure superheated steam would then be sent directly to the power plant turbine without disrupting the power plant boiler. The fluidized bed tubes would have to be designed specifically for this case as it is necessary to maintain high mass velocities to prevent burn-out of evaporation tubes. Each section of tubes would contain sufficient instrumentation to evaluate design parameters of heat transfer, hydraulic and pressure drop so that future fluidized bed boilers may be designed with confidence.

4. Bundle and Tube Removal from the Fluidized Bed

In conventional boilers, each pass (platen) penetrates the water wall at the inlet and outlet so that the tubes are headered outside the water wall in the relatively cold sections of the boiler. In the pressurized fluidized bed boiler it has been decided to header internally even though the headers are now a more expensive, thicker-walled alloy. This means that fewer penetrations of the water wall are required (two headers instead of 80 passes). It is estimated that removal of the entire tube

V. Design Problems and Solutions (continued)

4. Bundle and Tube Removal from the Fluidized Bed (continued)

bundle with internal headers will require two weeks and $10,000 vs. 3 weeks and $20,000 for external headers.

5. Start-up Heaters

To support combustion it is necessary to heat the combustion zone to at least 700 to 800°F.

An air preheater has been provided to preheat air to 1200°F. When the fluidized bed is held at a low level, the preheated air can heat the bed plus the tubes in a reasonable time interval to 1000°F. To avoid overstressing the grid an insulated plate is placed above the boiler nozzle connected to the preheater to prevent radiation damage. If additional heat input is required when the bed level is high or when the steam flows in the tubes at a high capacity additional heat may be supplied by firing three ignitor-combustor guns directly into the fluidized bed above the grid.

6. Shell Insulation

To contain combustion at high temperature and pressure it is desirable to reduce the temperature of the enclosure shell to a point where the allowable stresses are reasonable, i.e., less than 600°F. This may be accomplished by using internal refractory insulation, or alternately, the shell may be cooled by surrounding the combustion zone by water-wall tubes. The tubes are used to preheat or evaporate water, which means that the water-wall temperature is less than 670°F. The annular space between the water-wall and the pressure shell is cooled by combustion air.

V. Design Problems and Solutions (continued)

6. Shell Insulation (continued)

It has been decided to use water walls similar to conventional boilers for the following reasons:

a) The water walls in general can be designed for higher heat recovery and thermal efficiency than refractory insulation.

b) Water walls take up less space than insulation.

c) Insulation would have to be covered with a hard facing refractory to resist erosion.

d) Water walls can be built to take slight pressure differential.

e) Water walls reduce the structural steel requirement by acting as supports for coils in the bed and for the grid.

7. Steam Tube Orientation

Steam tubes may be positioned horizontally, vertically or at an angle. It may be expected that the position of the tubes can effect heat transfer rates, smoothness of fluidization and erosion. Heat transfer rates, as pointed out by Genetti, et al. (1), suffer when tubes are positioned at an angle. The same authors indicate that vertical bare tubes have slightly better heat transfer rates than horizontal tubes in the particular size range of 100 to 200 microns. However, for larger-size particles (400 microns), there is no difference in heat transfer between horizontal and vertical tubes at any velocity.

The heat transfer rate was calculated by the method Vreedenburg(2) for the normal capacity Case A-1. This method indicates a slightly better

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(1) Genetti, W.E.; Schmall, R.A. & Grimmett, E.S.
AIChE Symposium Series, Fluidization No. 116, Vol. 67, p. 90, 1971

(2) Vreedenburg, H.A., Chem. Eng. Sci., Vol. 9, p. 52, August 1958.
Chem. Eng. Sci., Vol. 11, p. 274 (1960)

V. Design Problems and Solutions (continued)

7. Steam Tube Orientation (continued)

heat transfer for vertical tubes than for horizontal. However, if the method of Wender and Cooper(1) for vertical tubes transfer rate is compared with horizontal tubes by the method of Vreedenburg, the horizontal tubes show a better heat transfer rate.

From the literature it is difficult to determine if horizontal tubes are superior to vertical. However, for deep fluidized beds of 10 to 30 feet, as designed into the developmental boiler, the horizontal tubes may exhibit superior heat transfer characteristics since horizontal tubes tend to act as baffles breaking the bubble growth which is detrimental to good heat transfer rates.

Tube position can also effect erosion. Zenz(2) indicated that erosion is a function of velocity to some power exponent ranging from 3 to 6, as well as the distance from nozzle to target. This author also points out that in pneumatic transport, there is often severe erosion on the outer radius of elbows due to the impact of the curved wall of the bend. Similarly, the impact of the fluidized particle will be greater against horizontal tubes than vertical tubes. For the horizontal configuration, it is necessary to weld a small impingement plate on the bottom rows of tubes. Similarly, for vertical tubes, the bottom 180° bends must be protected by welding a wear plate to the bottom U bends.

Both horizontal and vertical tubes must be well-supported or vibration will cause serious mechanical difficulty. We propose that the fluidized bed unit be constructed in such a manner that either horizontal or vertical bundles can be used with headering occurring internally to the water walls,

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(1)Wender, L. & Cooper, G.T., AIChE J., Vol. 4, p. 15, March 1958

(2)Zenz, F.A. & Othmer, D.F., "Fluidization and Fluid-Particle Systems", Reinhold Publish. Corp., New York (1960) p. 338

V. Design Problems and Solutions (continued)

7. Steam Tube Orientation (continued)

so that replacement need only involve cutting and rewelding the header instead of each pass of the tube bundle. For the test facility horizontal tubes were chosen.

8. Position of Cyclones

Cyclones in fluid bed operation can be positioned above the fluidized bed in the same vessel as the fluidized bed or they may be positioned externally to the fluid bed vessel. It has been decided to position the cyclones externally. This will allow an increase in flexibility by using multiple cyclones in parallel so that the removal of one, two or three units will maintain a high efficiency at all capacities. External installation will allow experiments on cyclones and measurements of cyclone efficiency.

9. Coal Injection

Coal feeding and control of rate and uniformity of feed rate is a difficult problem. It has been decided to use a Petrocarb-type of feeding system. The total coal feed is weighed into lock hoppers and then fed into a special injector vessel containing multiple nozzles to uniformly inject the coal by means of hydraulic transport.

10. Shell Size

It was decided to restrict the shell diameter of the development boiler to that used in a commercial design, i.e., the maximum capable of shipment by rail so that the vessel can be shop-fabricated. In this case the diameter of 12'0" was chosen and this allowed reasonable internal area for headers and flexibility for various pipes penetrating the shell. No advantage could be seen in increasing the diameter beyond 12'0" for the development plant boiler.

VI. Experimental Program

The experimental program and test procedures are the minimum required to meet the objectives of the demonstration boiler as outlined in the Introduction in Section I. The sequence of operation of the pressurized fluidized bed boiler including tests and experiments has been divided into the following phases:

1. Startup
2. Boiler Performance Test
3. Tests for Operability
4. Reliability Demonstration
5. Tests of Pollution Abatement
6. Tests of Long Range Objectives

Some of the tests can be performed concurrently. For instance, the heat transfer should be analyzed for every operation or test on the boiler.

In all phases it is planned to operate the boiler with a coal feed of Ohio Pittsburgh Number 8 Seam Coal. The sorbent will be BCR 1337 Dolomite. Testing other types of coal or sorbent will extend the test period.

1. Startup and Shutdown Procedure

Prior to the initial startup, careful and thorough preparation is a prerequisite for satisfactory performance eliminating much trouble and delay during the initial startup. A final inspection should be given to all vessels before bolting of the manways. Refractory-lined vessels of 12 feet in diameter or less and piping of monolithic construction are cured and dried by others. Depending on the actual site for this plant, the cyclone drum, D-120 may be too large to be shipped in one piece. In this case, D-120 will be field-fabricated and the refractory linings installed on site. The main air compressor, C-101, and air preheater, H-102, could be used for drying of the refractory

VI. Experimental Program

1. Startup and Shutdown Procedure (cont'd)

lining of this vessel. After curing and drying of refractory-lined vessel cracks may develop. Small cracks of refractory-lined vessels are normal. However, when the crack is larger than 1/8" in width and 1½" in depth, the crack shall be repaired prior to startup.

Particular attention must be given to the inspection of the Fluid-Bed Boiler. The wall tubes and horizontal tube bundle should be checked for signs of leakage. Care should be given to thorough cleaning of the instrument purge line. After the instrument lines have been cleaned, be sure that the proper restriction orifice plate has been put back on the purge line. Piping supplying purge or aeration medium other than instruments should be prepared in a like manner whenever particulate matter may be present.

During initial startup all instruments must be completely checked out. This is particularly important for the Fluidized Bed Boiler unit. The control valves should also be checked out for operability, i.e., stem travel, action on air failure, etc. All transmission systems for each instrument shall also be inspected.

Preliminary Preparation

Utilities required for the startup shall be verified that all are in service or in readiness. A thorough check for readiness of the following utilities or service is required:

a) Instrument air supplied to all instruments as required.

b) Electric power available for all drivers.

c) High pressure boiler feed water and saturated steam are available for the fluid bed boiler.

VI. Experimental Program (continued)

1. Startup and Shutdown Procedure (continued)

Preliminary Preparation (continued)

d) Medium pressure steam is available for Air Preheater, H-102.

e) Cooling water must be available. Cooling water flow may be established through the equipment required for startup.

f) Fuel oil should be made ready for the Air Preheater, H-102.

g) All fire fighting and other equipment.

h) Verify that all blinds are removed or is the normally open position for operation.

Establish Air Flow

Before running-in the compressors, all auxiliary systems shall be carefully inspected. Oil reservoirs, lubricators and oil lines shall have clean oil circulated for verification of cleanness. This oil should then be discarded and the proper lubricating oil supplied. During run-in of the compreesor, all controls of the lubricating system must be made to function correctly and satisfactorily. All alarms and safety devices must be verified as to proper settings and correct function.

At the completion of compressor run-in, the Main Air Compressor, C-101, shall be put into service. Due to the high discharge temperature of this compressors, a temporary air cooler may be required during the initial startup to minimize thermal shock to refractories. The air velocity in the fluidized bed boiler shall be maintained at 3 to 4 fps and the air temperature set at approximately 250°F to 300°F.

All refractory-lined vessels should be heated at this time. This is accomplished by opening the balance line on vessels D-112, 113, 114, 115 and 117 to admit the heated air or flue gas and crack open the vent valve on each of these vessels.

VI. Experimental Program (continued)

1. Startup and Shutdown Procedure (continued)

Establish Air Flow (continued)

At the same time, the Injection Air Compressor, C-103, shall be put into service to establish the required pressurizing and injection air for the Petrocarb system. The instrument purge air from the Package Purge Air Dryer, A-102, shall also be put into service.

Loading of Coal and Dolomite

Next, the coal and Dolomite Silos, D-102 & 3, shall be filled. The Lock Hoppers, D-105 and 109, and the Injection Hoppers, D-106 and 111, shall be made ready for startup. At this time, the Petrocarb's system shall be subject to thorough inspection and tests. Particular attention shall be given to the performances of the Coal Crusher, SR-101, Coal Dryer, RK-101, and the various conveying systems. At the completion of the initial tests of the Petrocarb system, the dolomite shall be injected into the boiler to a bed height of approximately four (4) feet.

Initial Startup

The air temperature to the boiler shall be increased gradually until it reaches the discharge temperature of the air compressor. At this time, saturated boiler feed water at 2400 psig shall be circulated through the wall tubes to the Steam Separator, D-110, and back to the power plant. Saturated steam at 2400 psig shall be admitted to the horizontal tube bundle at a reduced rate of approximately 70,000 lb/hr. Next, the Air Preheater, H-102, is put into service. The fluidized bed temperature shall be brought up very gradually by the air preheater at a rate not exceeding 100°F per hour, until a bed temperature of 1000°F to 1200°F is established. Next, one of the four coal injection lines should be

VI. Experimental Program (continued)

1. Startup and Shutdown Procedure (continued)

Initial Startup (continued)

placed into service at a minimum coal injector rate. As the coal combustion takes place, the air preheater firing rate shall be reduced. When it is determined that the coal combustion will maintain the fluidized bed temperature, the air preheater shall be taken out of service completely. During the initial startup, the bed temperature shall be maintained at around 1400°F to 1500°F. The fluidized bed level and boiler feed water and saturated steam feed rates shall be adjusted to maintain the bed temperature as the coal rate is increased.

The operation will be continued until the required coal injection rate is established.

Spent dolomite from the boiler will be discarded to the Spent Sorbent Lock Hoppers, D-112 and/or 113, and then to the Dolomite Cooler, RC-101, for disposal.

Normal Shutdown

The following shutdown procedure covers a normal, scheduled and complete shutdown such as would be required for turnaround and inspection.

Over a period of several hours, the coal rate to the boiler shall be reduced. During this time, the air rate shall also be cut back to maintain a low oxygen content in the flue gas. When the boiler bed temperature reaches 1000°F. The coal injection lines shall be cut off one at a time until the coal feed is completely cut off. The dolomite feed to the unit shall also be stopped. The compressed air, however, should be maintained to facilitate the withdrawal of the dolomite. When the bed temperature reached 650°F, the water quench to the Quench Pot, D-119,

VI. Experimental Program (continued)

1. Startup and Shutdown Procedure (continued)

Normal Shutdown (continued)

shall be taken out of service. The residual dolomite and fly-ash in the system shall be emptied to the Dolomite Cooler, RC-101. At the end of the operation, the boiler pressure shall be reduced gradually to atmospheric pressure to complete the shutdown.

Schedule

The schedule for startup after acceptance of the boiler plant from the contractor allows four (4) months for initial startup. This time period allows for repairs and minor modifications as well as training of operators.

2. Boiler Performance Tests

The performance test for the Fluidized Bed Boiler unit shall be adopted from the American Society of Testing Materials Power Test Code(1). The Code is intended primarily for conventional steam generation units. Minor modifications, therefore, must be made for the performance tests of the Fluidized Bed Boiler. Figure VII offers a format for evaluating the Fluidized Bed Boiler unit performance. The major modifications included in this form deals with the reaction and sensible heats of SO_2 sorption, and formation of CaO and MgO, etc. Other modifications are minor and are self-explanatory.

For a large commercial unit, the efficiency of the power generation will be high due to the inclusion of waste heat boiler, turbine expander, as well as turbine steam generation. However, for the demonstration unit

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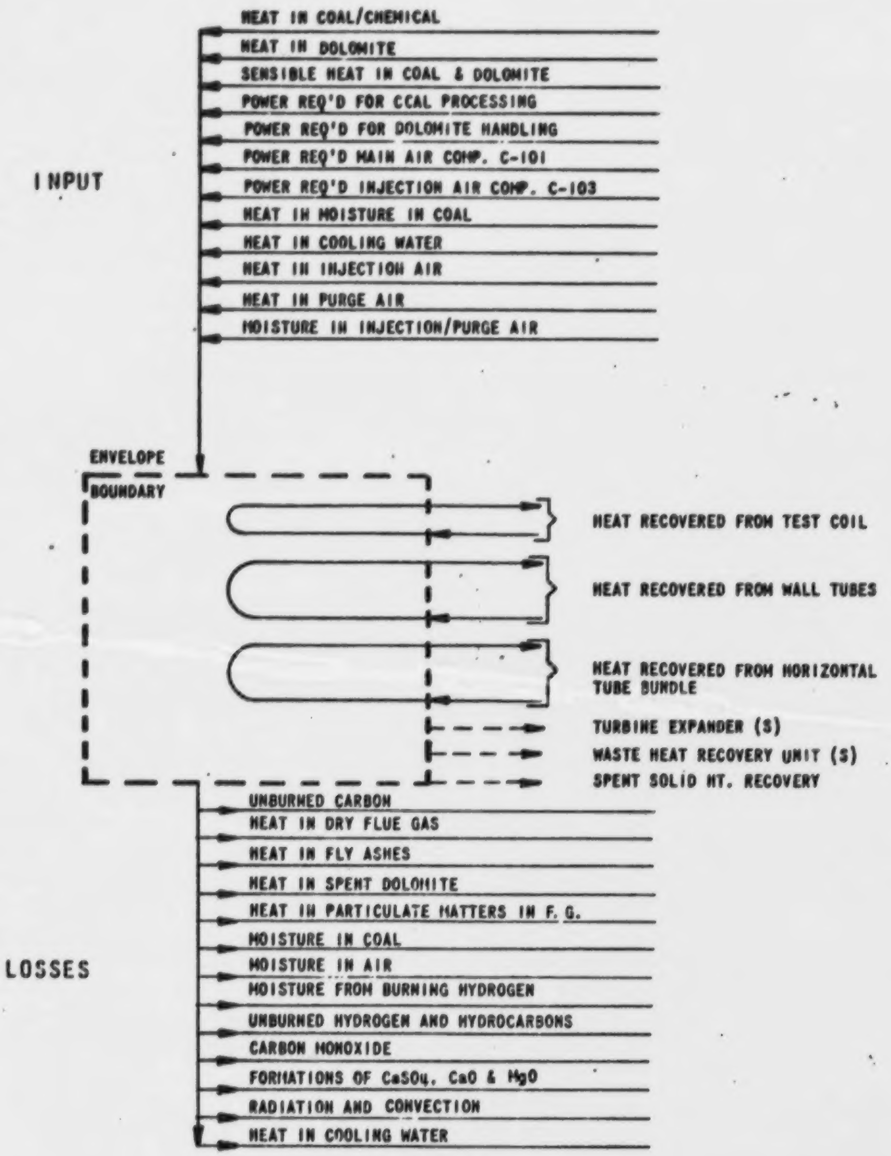
(1) American Society of Mechanical Engineers PTC 4.1-1964 Power Test Codes Steam Generation Units, herein, is believed to be in general agreement and intention of the ASME Code.


INPUT
HEAT IN COAL/CHEMICAL
HEAT IN DOLOMITE
SENSIBLE HEAT IN COAL & DOLOMITE
POWER REQ'D FOR CCAL PROCESSING
POWER REQ'D FOR DOLOMITE HANDLING
POWER REQ'D MAIN AIR COMP. C-101
POWER REQ'D INJECTION AIR COMP. C-103
HEAT IN MOISTURE IN COAL
HEAT IN COOLING WATER
HEAT IN INJECTION AIR
HEAT IN PURGE AIR
MOISTURE IN INJECTION/PURGE AIR
ENVELOPE BOUNDARY
HEAT RECOVERED FROM TEST COIL
HEAT RECOVERED FROM WALL TUBES
HEAT RECOVERED FROM HORIZONTAL TUBE BUNDLE
TURBINE EXPANDER (S)
WASTE HEAT RECOVERY UNIT (S)
SPENT SOLID HT. RECOVERY
LOSSES
UNBURNED CARBON
HEAT IN DRY FLUE GAS
HEAT IN FLY ASHES
HEAT IN SPENT DOLOMITE
HEAT IN PARTICULATE MATTERS IN F. G.
MOISTURE IN COAL
MOISTURE IN AIR
MOISTURE FROM BURNING HYDROGEN
UNBURNED HYDROGEN AND HYDROCARBONS
CARBON MONOXIDE
FORMATIONS OF CaSO4, CaO & MgO
RADIATION AND CONVECTION
HEAT IN COOLING WATER

OUTPUT = INPUT - LOSS

DEFINITION: EFFICIENCY (PERCENT) $\eta_g (\%) = \frac{\text{OUTPUT}}{\text{INPUT}} \times 100$

Figure VII

HEAT BALANCE OF
PRESSURIZED FLUIDIZED BED BOILER
FOR
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURG PENNSYLVANIA

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APPROVED BY:				

REVISION

ORDER NO. 11-52331

FORM 383-85-E

VI. Experimental Program (continued)

2. Boiler Performance Tests

these facilities have been deleted for reason of economy. To have a meaningful determination of the Fluidized Bed Boiler efficiency, the above facilities should be accounted for. A time period of one month is allowed for the performance tests.

3. Tests for Operability

A series of tests are required to determine operability and response of the unit. Operating factors such as capacity turndown, stability at low capacity, response and tracking, testing for entrainment, heat transfer, fluidization, removal efficiency of particles from flue gas, efficiency of combustion and corrosion-erosion tests are required.

After the boiler performance test at normal (A-1 Case) conditions, it is necessary to test turndown from normal capacity with combustion in the boiler and all auxiliaries operating. Turndown of coal feed (with its proportionate air quantity) will drop the temperature of the fluidized bed since the heat transfer area is fixed and the transfer rate in a fluidized bed is approximately constant with velocity. A drop in temperature of the bed below 1400°F may tend to reduce the sulfur removal capacity of the dolomite. To maintain a temperature above 1400°F with adequate sulfur removal capacity in the bed, it may be necessary to drop the level in the bed as the coal feed is decreased. At some low capacity the fluidization and heat transfer will suffer due to low velocity and low level of the bed. In addition to capacity turndown, it is desirable to test fluidized bed pressure turndown. The pressure can be reduced from 160 psig to a few psig above atmospheric pressure. The compressor will still operate at its design point, however, most of the gas will be bypassed

VI. Experimental Program (continued)

3. Tests for Operability (continued)

around the boiler and the coal feed will be reduced from normal rate to the lowest controllable rate, i.e., approximately 10% of normal. A one-month period of operation is required to evaluate turndown. Turndown tests should not be performed when the boiler is operating under evaporation mode due to the danger of loss of nucleate boiling promoting tube burn-out due to low flow and low velocity through fixed-sized tubes.

Both heat transfer and hydraulics, which includes the determination of flow vs. pressure drop for both the steam side as well as the fluidized bed side, and fluidization characteristics such as slugging of the bed, clinkering, etc., will be evaluated during every experimental run and therefore separate runs are not required.

Operation to test entrainment can be effected by lowering an internal air-cooled chimney from the outlet of the bed into the free space above the bed. The internal chimney is welded or cut to fix the disengagement height. This will allow an evaluation of the effect of freeboard for various velocities on entrainment. A total elapsed time of four (4) months may be necessary for this operation due to the down-time required to modify the internal chimney.

Particulate removal efficiency can be evaluated at different velocities of flue gases. Tests can be performed by sampling between the boiler and the Ducon cyclone, between the Ducon and the Aerodyne cyclone and also after the Aerodyne cyclone and after the quench. Velocity can be varied by varying flue gas quantity, by changing the number of cyclones in the flue gas stream and also by bypassing clean air into the cyclones. Two (2) months are required for testing cyclone efficiencies.

VI. Experimental Program (continued)

3. Tests for Operability (continued)

The efficiency of combustion will be evaluated for each test procedure. Steam production, coal feed rate, amount of carbon in the entrained particulate, unburned CO and hydrogen in the gas will be analyzed for each test to calculate the combustion efficiency.

Corrosion-erosion testing will proceed during all tests by inspection of all existing equipment between tests, as well as by inserting a special test loops in the fluidized bed. Each loop will usually be constructed of a single material such as TP304H (18-8) to evaluate erosion-corrosion, as well as welding metallurgy. Loops can be tested during other boiler test operations.

In addition to the test loop, the entire boiler unit will confirm materials selection and bundle design by periodic inspection of those portions exposed to the fluidized bed by measuring metal thickness. An important part of the materials testing will be derived from the operation of the turbine cascade tester. Separate test periods for erosion are not required as erosion will be determined after every shutdown.

Heat Transfer and Fluidization

Various temperature points have been provided for both the horizontal tube bundle and the wall tubes. The heat transfer rates of the dense bed section, the dilute phase as well as the section immediately above the dense bed can be computed.

Operating a fluidized bed unit with relatively large particle size may sometimes result in slugging problems. The closely-packed horizontal tube bundles will reduce coalescence and slugging tendency. Radioactive probe has been provided. The probe could be located at various elevations of the unit to monitor the slugging height.

VI. Experimental Program (continued)

3. Tests for Operability (continued)

The movement of individual particles past the tubes will be of importance. Short-lived radioactive particles may be used to study the movement of the particles, the turn-over rate, residence time, etc., through the horizontal tube bundle, in a manner similar to their use in commercial catalytic fluid bed systems.

Three (3) sample connections have been provided on the dense bed and one on the spent dolomite line. With these samples it will be possible to study the degree of particle size separation, at various heights of the bed.

4. Reliability Demonstration

In the process industry a new plant is usually accepted as operable if the installation can be demonstrated to operate at full capacity for some minimum period, such as ten days. However, in order to demonstrate reliability, a developmental boiler must operate at full capacity for an extended period of time. It has been assumed that a one-year period of time will be required for operation under normal capacity (A-1 design case) to adequately demonstrate reliability.

5. Tests for Pollution Abatement

Those factors in the operation of the pressurized fluidized bed boiler effecting SO_2, NO_x and particulate matter are:

- Calcium/sulfur ratio
- Bed temperature
- Bed height
- Excess O_2 in flue gas
- Operating pressure
- Feed and removal locations

VI. Experimental Program (continued)

5. Tests for Pollution Abatement (continued)

In order to test the effect of the above variables on emissions of SO_2 , NO_x and particulates, a set of experiments have been developed.

Case A-1 will offer an ideal case for pollution control tests. In this case the excess O_2 in the flue gas can be increased to 5 mol%. The normal bed depth of approximately nineteen (19) feet will offer adequate latitude to study the effects of bed depth. The suggested parameters to be used in this study will be as follows:

Bed Temp. °F	1350	1450	1550	1650	1750
Ca/S Mol Ratio	2	3	4	5	6
Bed Depth, Ft.	9	11.5	14	16.5	19
Ex O_2 in Flue Gas,Mol %	0	1.25	2.5	3.75	5
Operating Press. Atm. Abs.	5	6.25	7.5	8.75	10

The above parameters may be evaluated by means of 33 experiments. It is not our intent to commit the operation of the developmental boiler to the full 33 experiment block, since preliminary operation of the boiler will show that some of the proposed factorial tests may not provide useful data.

6. Test of Long Range Objectives

The long range objectives studies include testing those factors which may improve steam generating efficiency, reduce SO_2, NO_x and particulate pollution and will demonstrate the operability of a complete steam generation facility.

a) Study of different coals and sorbents to improve pollution removal efficiency.

b) Study of granular bed filter or alternate systems to increase particle removal efficiency.

VI. Experimental Program (continued)

6. Test of Long Range Objectives (continued)

c) Study of turbo-expander operating characteristics to recover as much compression power as possible, including expander control and its interaction with the air compressor.

The turbo-expander will demonstrate operability and control. Metallurgy will be determined by operation of the turbine cascade tester.

d) Alternate tube bundle designs can be studied to improve space utilization, heat transfer, reduce tube cost and perhaps reduce erosion.

e) High steam temperature and pressure, while increasing capital investment, should increase power generating efficiency. The feasibility of designing the fluidized bed developmental boiler for steam at 6500 psig and 1300°F was investigated. An advantage of operating at extreme conditions in a fluidized bed is that the tube metal temperature can be kept relatively low allowing a reasonable design stress on the tubes. If the fluidized bed temperature is assumed to operate at a maximum of 1750°F when the steam temperature is 1300°F., the skin temperature will be less than 1360°F.

An Inconel material Number 625 (ASTM B444) annealed has a rupture stress of 18,000 psi for 50,000 hours of service according to Inco Bulletin T-420. If an allowable stress of 15,000 psi is assumed and with a tube thickness tolerance of ± 15%, the O.D. of a 1" I.D. tube would be less than 1-3/4". This thickness-diameter ratio is near the limit for hot bending of Inconel 62[illegible] At any thickness, powerful equipment is required for heat forming which can only be done in the 1950 to 2150°F. range.

VI. Experimental Program (continued)

6. Test of Long Range Objectives (continued)

e) (continued)

The developmental boiler has a small test loop which can be designed for high temperature and pressure steam generation. In addition to the test loop, some auxiliary equipment such as a high-head plunger pump, a hairpin exchanger to preheat water and a quench to reduce steam temperature, plus a pressure reducing station and proper instrumentation to monitor and control flow, pressure and temperature, must be provided. After successful operation of the test loop, a small bundle could be provided in the developmental boiler for actual steam generation including preheat, evaporation and superheat in the fluidized bed boiler.

f) Study fluidized bed combustion at higher pressures. The plant is mechanically designed to operate at 320 psig in the fluidized bed. However, to increase pressure from 160 psig to 320 psig it is necessary to insert an additional centrifugal compressor on the combustion air (Compressor C-102).

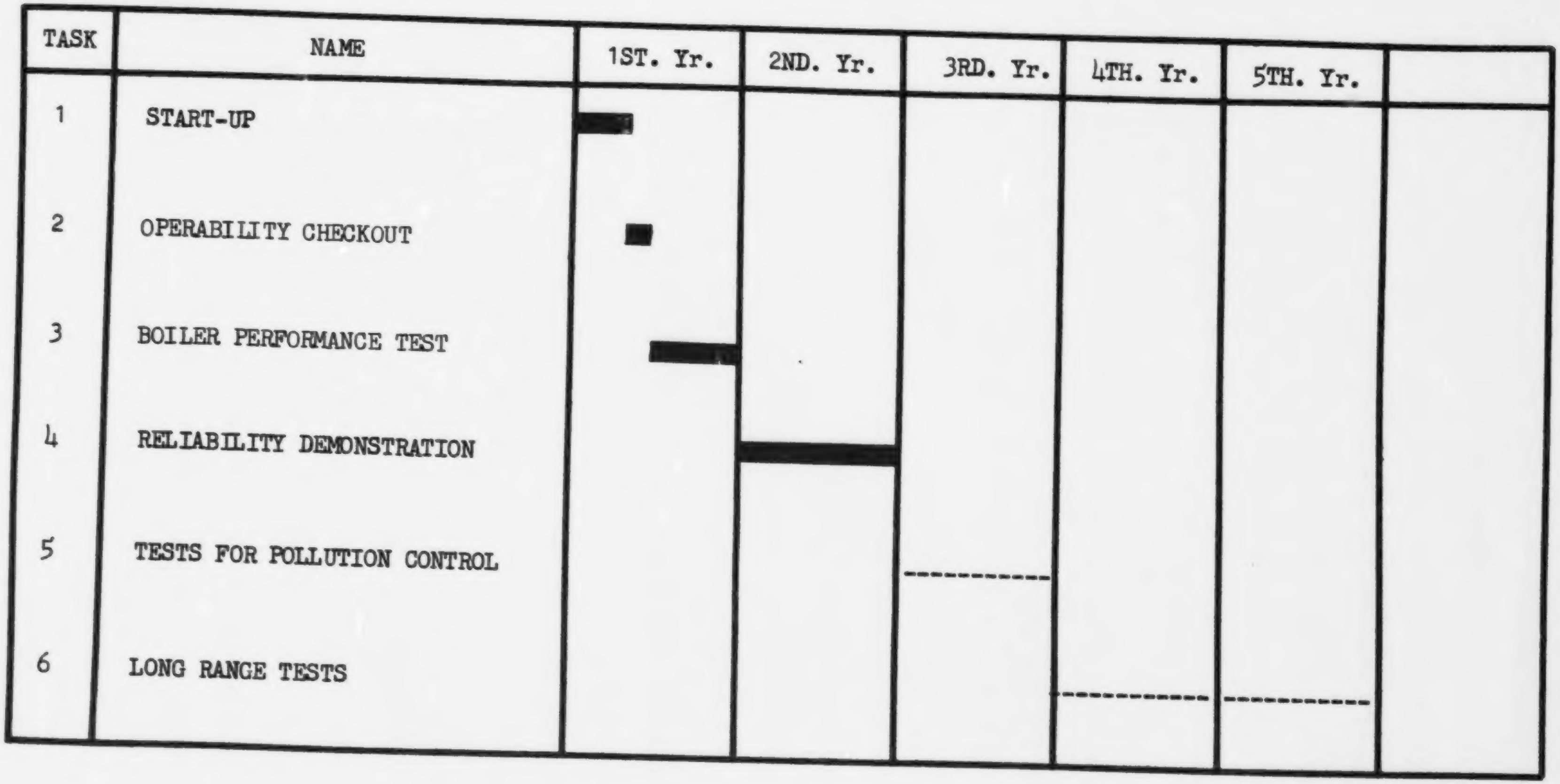
g) Demonstrate operability of the complete power plant installation. This will require additional fluidized beds for preheat evaporation, superheat as well as for reheat. The water side will be piped in series through the fluidized beds. The coal, dolomite, air and flue gas will be piped in parallel. The beds do not have to be stacked but all three can be built at grade level. Additional equipment besides the turbo-expanders will be steam turbo-generator, condenser, boiler feed water treatment, deaerator, boiler feed water pumps, electrical switch gear and transformer, heat exchangers.

Form No. 13D-135

WESTINGHOUSE RES. LAB
PRESSURIZED FLUIDIZED BED COMBUSTION BOILER
PITTSBURGH, PA.

FIGURE VIII a

OPERATING SCHEDULE



VII. Plant Construction

1. Safety and Emergency Control System

The boiler emergency shutdown trip system is shown on Figure VIII-b. In general, the procedure to be followed in an emergency is to follow the pattern of a normal shutdown as closely as possible except where particular emergency conditions require more drastic action.

a) Low Flow of Boiler Feed Water to Tube Bundle

When the boiler feed water to the tube bundle drops to its low flow set point, an alarm will sound. This will allow the operator an opportunity to correct the situation. However, should the boiler feed water flow rate continue to fall to its low-low flow set point, the low-low flow switch (FSLL) on the boiler feed water circuit trips the injection and pressuring air to the Injection Drum, D-106, to cut off the coal feed to the boiler. The switch will also actuate one point of a multi-point, multi-variable alarm annunciator to indicate such an emergency has taken place. The low-low flow switch shall be set to avoid high tube skin temperature of the tube bundle. During evaporation operation the flow switch shall be set within its minimum nucleate boiling range. When it is determined that adequate boiler feed water cannot be obtained, the unit will shut down under normal shutdown procedure.

b) Low Flow Saturated Steam to Tube Bundle

The same type of protection has been provided for the saturated steam circuit to the tube bundle as that provided for boiler feed water. The coal feed to the boiler will be cut off when the saturated steam reaches its low-low flow set point. This is necessary to avoid excess tube skin temperature of the bundle.

VII PLANT CONSTRUCTION (continued)

1. Safety and Emergency Control System (continued)

c. Low Flow of Boiler Feed Water to Wall Tubes

The wall tubes of the boiler are also protected against abnormal low boiler feed water flow rate. The low-low flow switch will trip the coal feed to the boiler. The low-low flow switch (FSLL) should be set within its minimum nucleate boiler range.

d. Tube Bundle Rupture

In the event of a tube leak or rupture of the tube bundle, the high pressure boiler feed water or steam to the unit must be cut off to protect the boiler. The flow rate of the boiler feed water or saturated steam to the unit is continuously monitored against the corresponding preheated boiler feed water, saturated steam or the superheated steam product. When the flow differential relay senses an abnormal difference in flow rates of the two streams, the high flow differential switches,(FDSH) will cut off the boiler feed water or saturated steam as well as the coal feed to the boiler.

e. Water Wall Tube Rupture

The pressure drop data across the water wall tube will be monitored continually. In the event of a wall tube leak or rupture, the pressure drop across the wall tubes will drop and the low pressure differential switch (PDSL) will trip the boiler feed water to the wall and coal injection to the boiler.

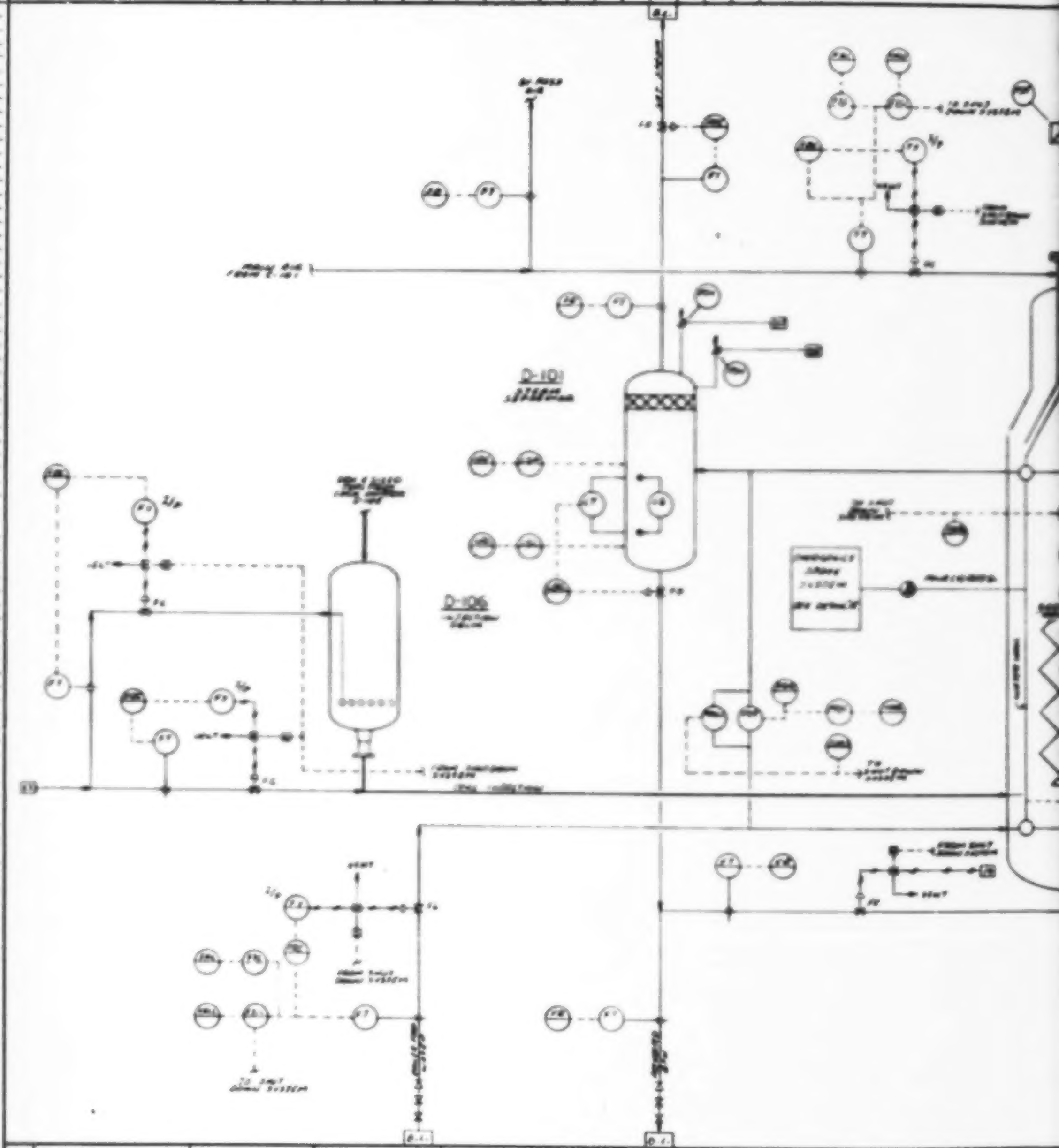
f. Dilute Phase High-High Temperature

The boiler bed temperature is controlled by coal injection rate to the unit. The dilute phase of the unit may at times experience higher temperature than the bed due to possible after-burning. A high temperature alarm and emergency water spray system have been provided on the dilute phase to control its temperature. However, should the dilute phase temperature continue to climb, a high-high temperature switch, (TSHH) will trip off the coal injection to the boiler.

A

BOILER SHUTDOWN TRIP SCHEDULE

	FIRST OUT ALARM	SHUT DOWN ALARM	SHUT DOWN OIL INJECTION	SHUT DOWN [illegible] INJECTION	SHUT DOWN [illegible]	SHUT DOWN MAIN AIR	SHUT DOWN [illegible] WATER WALL	SHUT DOWN [illegible] BUNDLE	SHUT DOWN [illegible]
LOW FLOW BFW TO TUBE BUNDLE	X	X	X						
LOW FLOW SAT STM TO TUBE BUNDLE	X	X	X						
LOW FLOW BFW TO WALL TUBES	X	X	X						
TUBE BUNDLE RUPTURE	X	X	X					X	X
WATER WALL TUBE RUPTURE	X	X	X				X		
DILUTE PHASE HIGH HIGH TEMP	X	X	X						
LOW PRESSURE FLUE GAS	X	X	X			X			
LOW FLOW MAIN AIR	X	X	X	X					
POWER FAILURE	X	X	X	X	X				
COOLING WATER FAILURE	X	X	X	X	X	X			
MANUAL SHUT DOWN	X	X	X	X	X	X			
SUPERHTD STM HIGH HIGH TEMP	X	X	X						



LEGEND

COOLING WATER SUPPLY
COOLING WATER RETURN
H.P. STEAM
STEAM INTERMEDIATE PRESS.
L.P. STEAM
EXHAUST STEAM
POTABLE WATER
PLANT AIR
INSTRUMENT AIR
H.P. CONDENSATE
CONDENSATE
TREATED WATER
FUEL OIL
FUEL GAS
CLEAN WATER SEWER
OILY OR DIRTY WATER SEWER
PROCESS SEWER
SANITARY SEWER
FIRE WATER
FLUSHING OIL
PUMPOUT
PURGE GAS
BLOWDOWN
FLARE
TO ATMOSPHERE
INERT GAS
INJECTION AIR

ITEM NO.
SERVICE
SURFACE
INSULATION
REVISIONS

B

VII-2-a

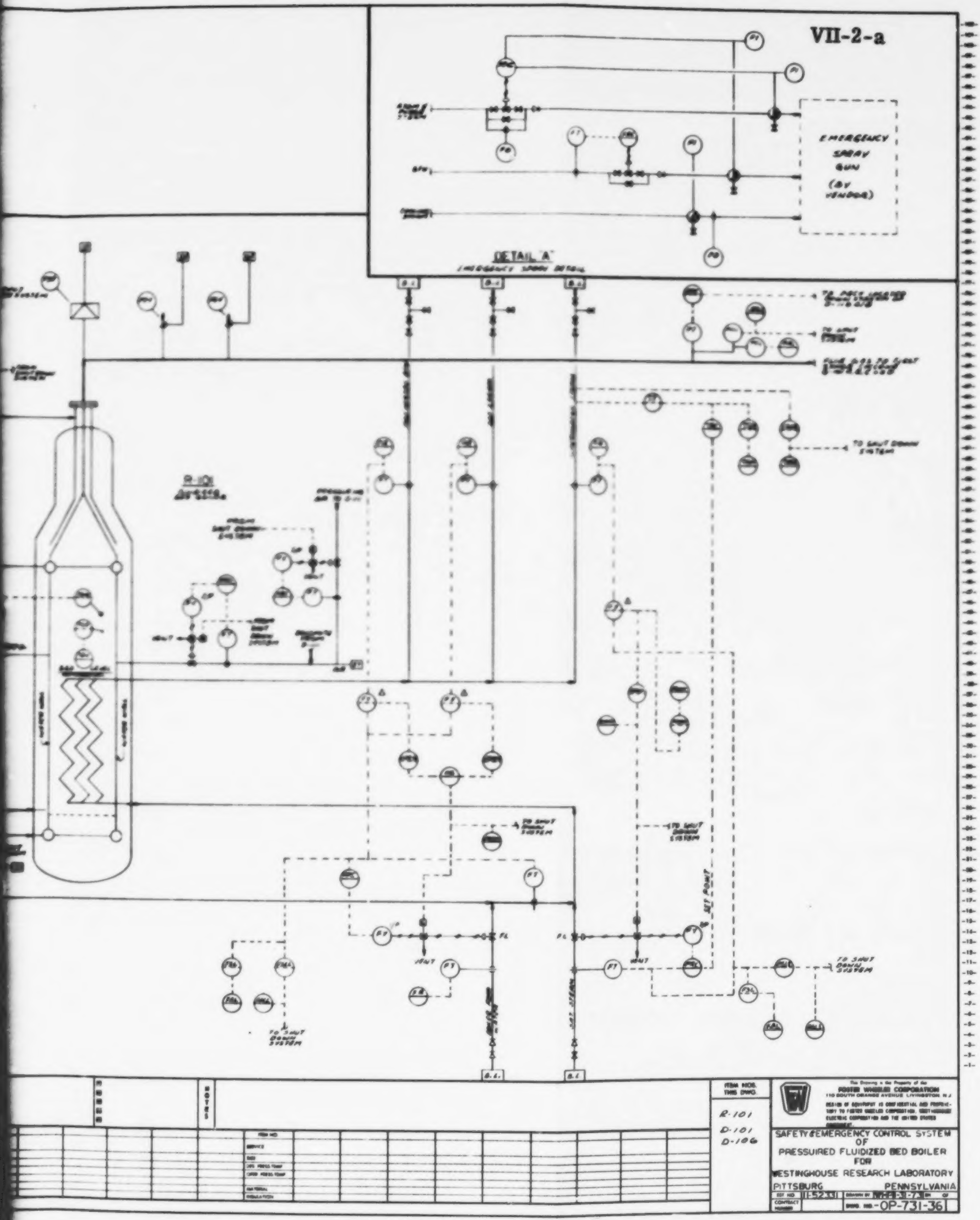


Figure VIII-b

VII. PLANT CONSTRUCTION (continued)

1. Safety and Emergency Control System (continued)

g. Low Pressure Flue Gas

A loss of flue gas pressure due either to back pressure control valve or rupture disc failure, should cut off the main air and coal injection to the boiler. This is necessary to avoid an excessive superficial velocity through the unit to control the dolomite elutriation loss.

h. Loss of Main Air

On loss of main air from the Main Air Compressor, C-101, the low flow switch from the main air will cut off the coal and dolomite to the boiler, followed by normal shutdown procedure.

i. Power Failure

During a power failure, emergency power shall be made available for the electronic instruments, solenoid actuators and the slide valves. Motor driven compressors, pumps, spent dolomite cooler, RC-101, and the coal/dolomite preparation and injection system will be inoperable. The safety circuit is so arranged that on trip of the circuit, coal and dolomite injection to the boiler will be cut off. An interlock system will be provided on the spent dolomite cooler, RC-101, to shut off all spent solids to the cooler during power failure.

j. Cooling Water Failure

Upon failure of the cooling water, the main air compressor, C-101, and the injection air compressor, C-103, will be shut down due to excessive discharge temperatures. The loss of main air will in turn cut off the coal injection to the boiler. When the spent dolomite cooler, RC-101, senses a low flow of cooling water, the low flow switch will cut off all spent solids to the cooler and shut off the fresh dolomite to the boiler.

VII PLANT CONSTRUCTION (Continued)

1. Safety and Emergency Control System (continued)

k. Loss of Instrument Air

All control valves during instrument air failure will fail in a safe manner. The coal and dolomite injections to the boiler will be cut off. Control valves for the boiler feed water or saturated steam to the tube bundle or water walls will be in locked position and continuously admitting boiler feed water or saturated steam through the tubes. The main air compressor,(C-101),will be taken out of service.

l. Manual Shutdown

The unit can also be brought down manually through hand switches. One hand switch will be located on the instrument board, and another one mounted locally. In the event of a fire, failure at the main power plant or any other reason, the manual shutdown switch will trip the safety circuit to cut off coal/dolomite to the boiler, block off spent solids to the spent dolomite cooler, (RC-101), and shut down the main air to the unit.

2. Utilities

Table XI summaries the utility requirements for four cases.

Case	Coal Capacity TPD	Design Pressure PSIG	Inclusion of Expander and C-102	Location
I	264	160	No	) Adjacent) to a Power) Plant
II	396	320	No	
III	396	320	Yes	
IV	396	320	NO	Stand Alone

TABLE NO. IX

UTILITY SUMMARY

CASE NO.	I	II	III	IV
Coal Feed Rate TPD	264	396	396	396
Fluid Bed Pressure PSIG	160	320	320	320
Inclusion of Expander and C-102 Compressor	No	No	Yes	No
Dolomite TPD	432	648	648	648
I Power in KW				
a) 13.2 KV, 30,60	15,704	21,221	21,221	21,221
b) 4.16 KV, 30,60	746	746	3,838	3,827
c) 440 V, 30,60	92	110	110	380
d) 110 V, 30,60	40	40	40	60
TOTAL POWER, KW	16,582	22,117	25,209	25,488
II Cooling Water GPM	2,885	4,044	4,631	*
III Treated Water	57	85	85	**
IV Fuel Oil MM Btu/Hr	3.17	4.76	4.76	4.76
V Cooling Tower Make up Water GPM	-	-	-	800

* Stand-alone unit contains own cooling towers requiring only makeup water at 5% of circulation rate.

** Sttand-alone unit has demineralizer to produce both quench and boiler feed water.

VII. PLANT CONSTRUCTION AND OPERATION (continued)

3. Plot Plant and Elevations

Plot plan and elevations are shown on drawings OP-721-588, 589, & 590. The plot plan was based upon the assumption and that the pressurized, fluidized bed boiler would be located adjacent to an existing power plant. Dolomite would be transported to the plant site by rail. The dolomite would be dry and double-screened. Covered rail hopper cars would be required and unloading would occur under a covered shed to prevent wetting by the rain. Coal may be introduced by conveyor from the utility plant's stock pile or it may arrive by open hopper rail cars. Steam and boiler feedwater are piped from the development boiler to the Utility Plant. Spent dolomite and ash are sent to the utilities ash disposal system by conveyor.

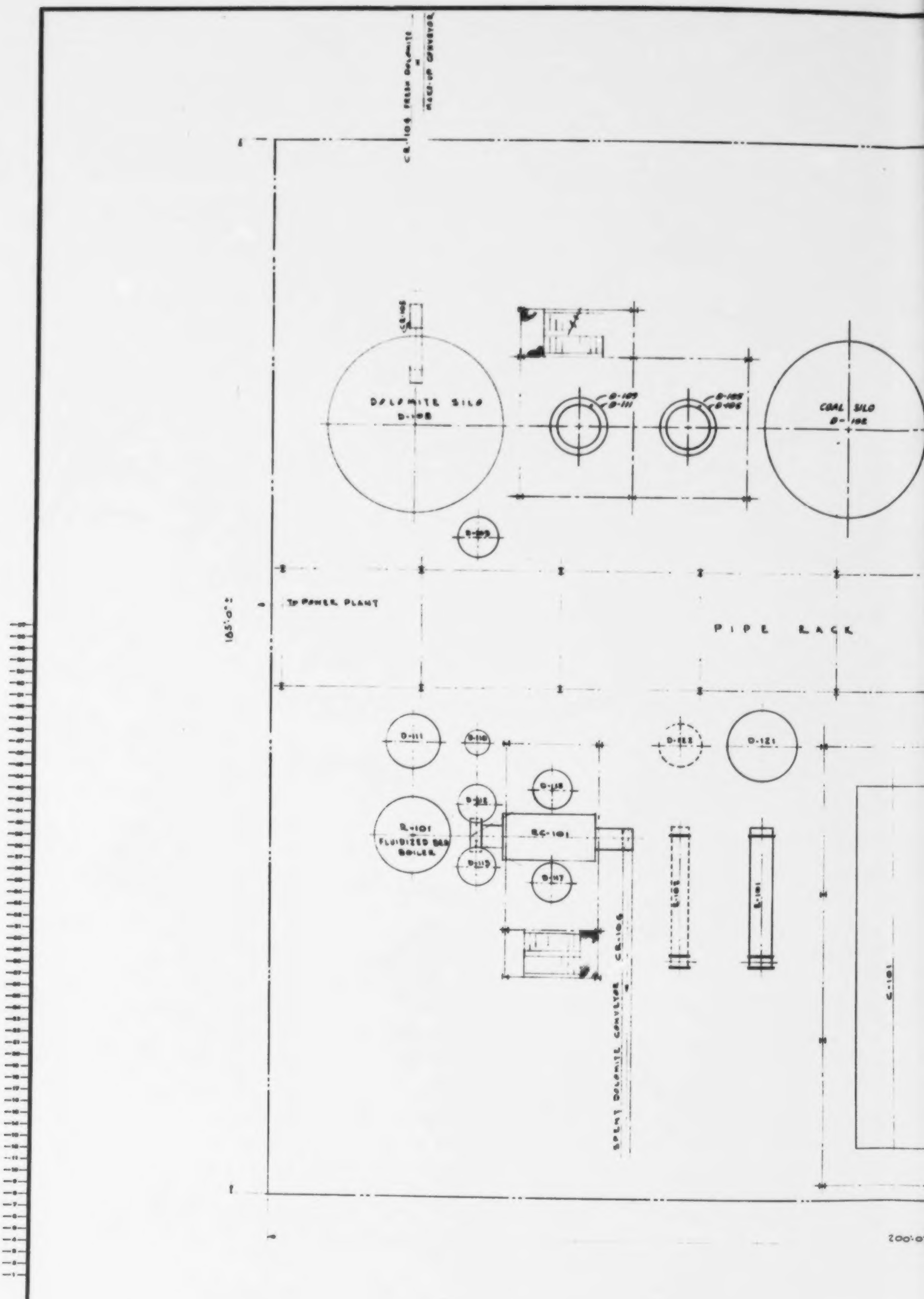
4. Schedule of Design and Construction

The schedule of design and construction is hown in Figure X. Completion of design and construction will require 20 months.

5. Cost Estimate and Economics

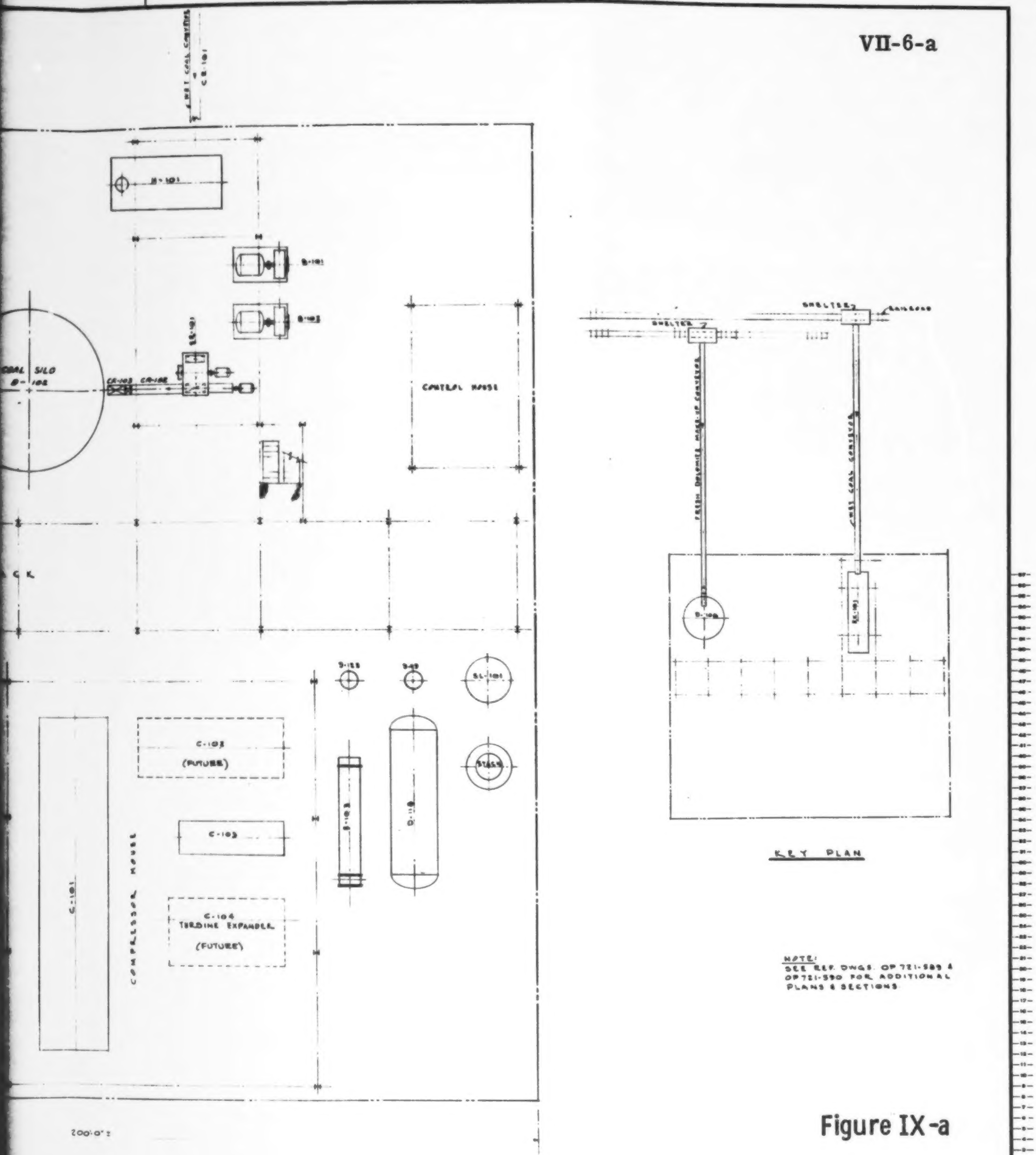
A series of cost estimates are presented for various capacities and design pressures. Case I has a plant capacity of 22,000 lbs/hr coal feed (A-1 Material Balance) and a design pressure of 170 psig in the boiler. Case II refers to 50% higher capacity of 33,000 lbs/hr coal feed (A-3 Material Balance) and an operating pressure of 320 psig but minus the high pressure compressor C-2 and minus the turbo-expander C-4. Case III at 33,000 lbs/hr of coal feed and 320 psig includes the high pressure compressor and expander. Case IV refers to a stand-alone boiler not adjacent to a power plant.

A


CR-104 FRESH DOLOMITE
MAKE-UP CONVEYOR
CR-105
DOLOMITE SILO
D-108
D-109
D-111
D-105
D-106
COAL SILO
D-102
D-103
TO POWER PLANT
185'-0"
PIPE RACK
D-111
D-110
D-122
D-121
D-118
D-112
R-101
FLUIDIZED BED
BOILER
RC-101
D-113
D-117
CR-106
SPENT DOLOMITE CONVEYOR
E-102
E-101
C-101
200'-0"

B

VII-6-a



NOTE:
SEE REF. DWGS. OP721-589 &
OP721-590 FOR ADDITIONAL
PLANS & SECTIONS.

Figure IX-a

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PLOT PLAN
PRESSURIZED FLUIDIZED BED BOILER
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PA.

DRAWN BY: JR. [illegible] SCALE 1/8" =1'-0" CUST. NO. 11-52331 DWG. NO-OP721-588

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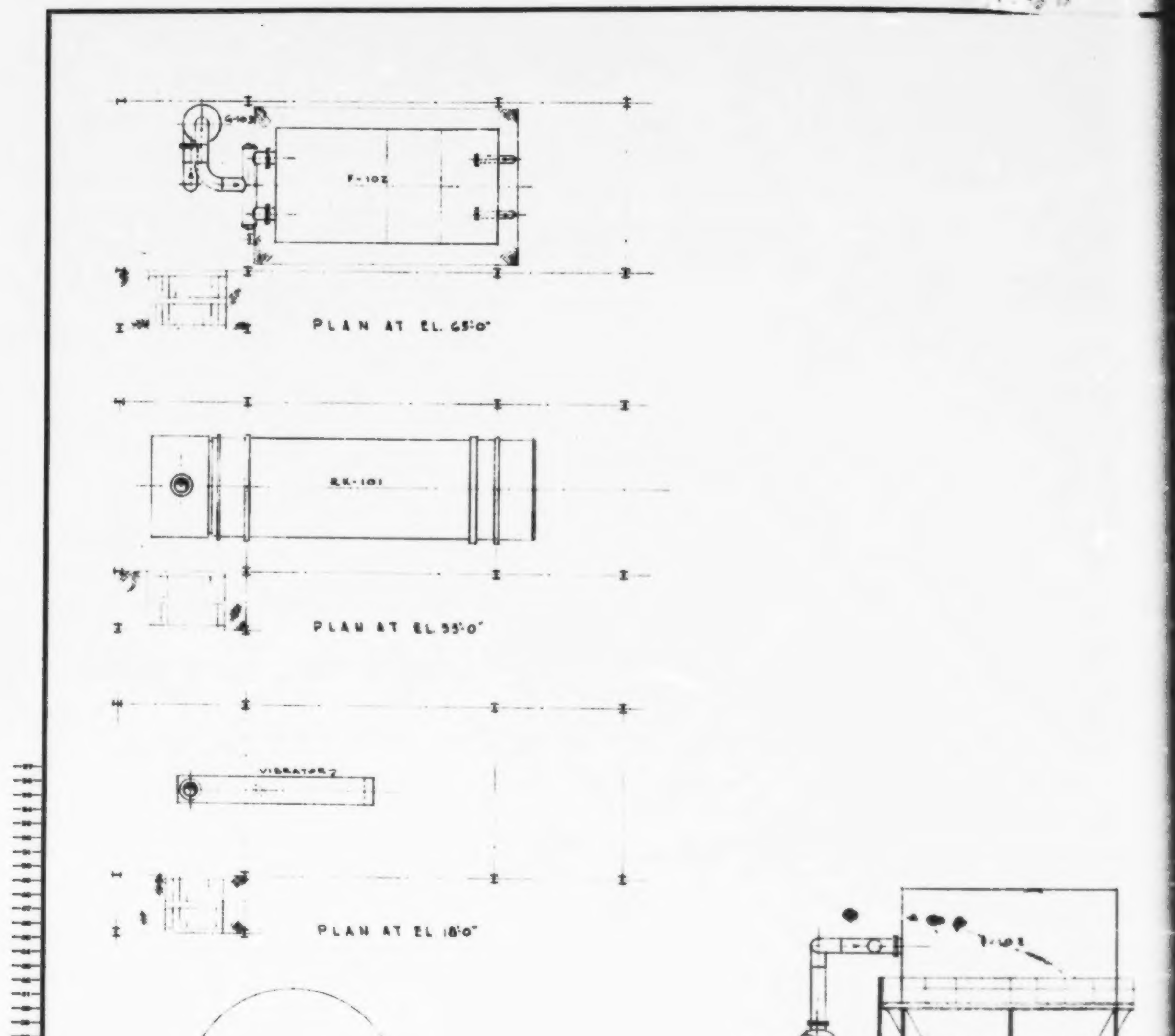
G-103
F-102
PLAN AT EL. 65'-0"
RK-101
PLAN AT EL. 55'-0"
VIBRATOR
PLAN AT EL. 18'-0"
D-102
CR-103
CR-102
SK-101
D-102
D-101
H-101
"A"
"A"
PLAN AT GRADE
F-102
G-103
EL. 65'-0"
RK-101
EL. 55'-0"
VIBRATOR
EL. 18'-0"
SK-101
D-102
D-101
SECTION "A-A"

B

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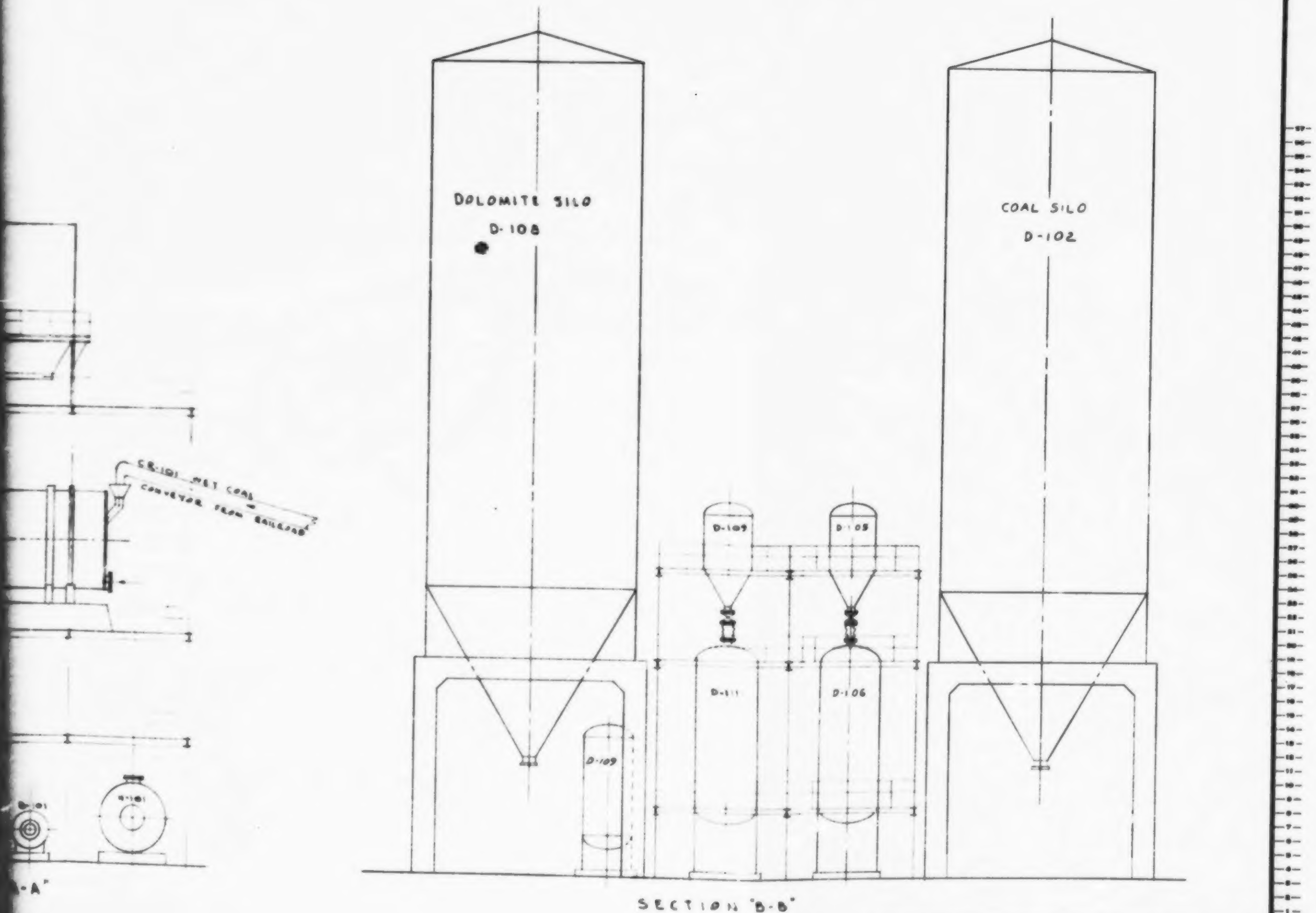

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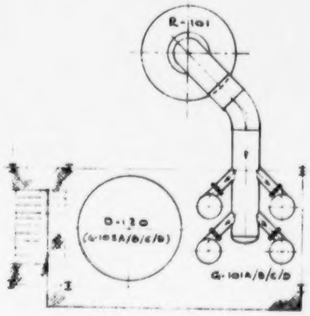
PLANS & SECTIONS
PRESSURIZED FLUIDIZED BED BOILER
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PA

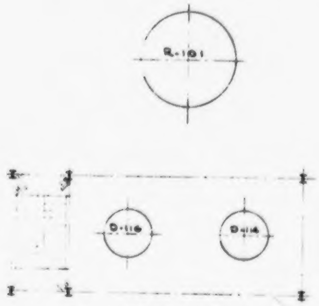
JR [illegible] 1/8" CONT. NO. 11-52851 DWG. NO. OP721-589

Figure IX-b

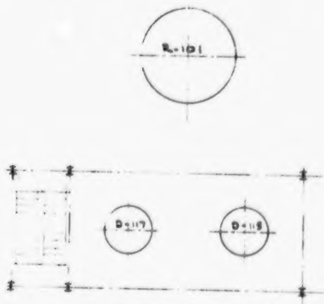
A



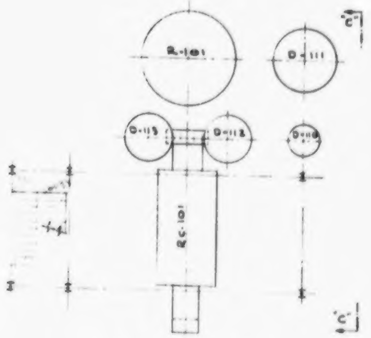
PLAN AT EL 95'0"



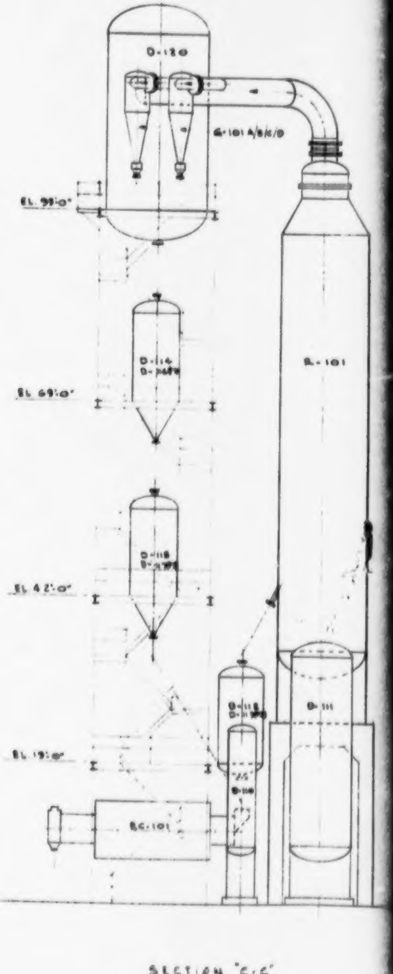
PLAN AT EL 69'0"



PLAN AT EL 42'0"



PLAN AT GRADE



SECTION "C-C"

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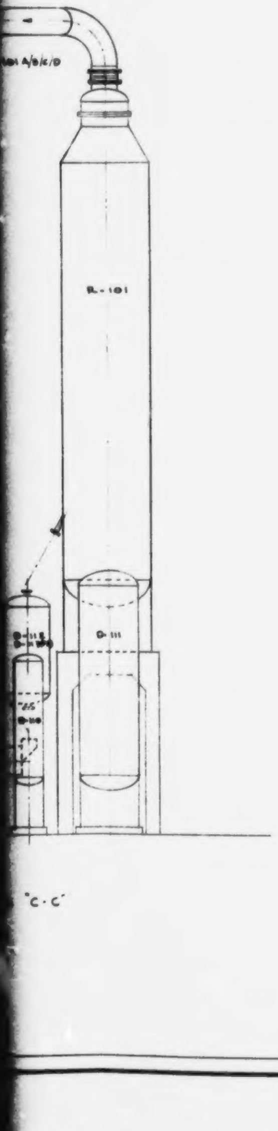

Figure IX-c

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PLANS & SECTIONS
PRESSURIZED FLUIDIZED BED BOILER
WESTINGHOUSE RESEARCH LABORATORY
PITTSBURGH PA.

DRAWN BY: JR 9/4/72 SCALE 1/8" = 1'-0" ORD. NO. 11-52331 DWG. NO. OP721-590

FORM NO. [illegible]

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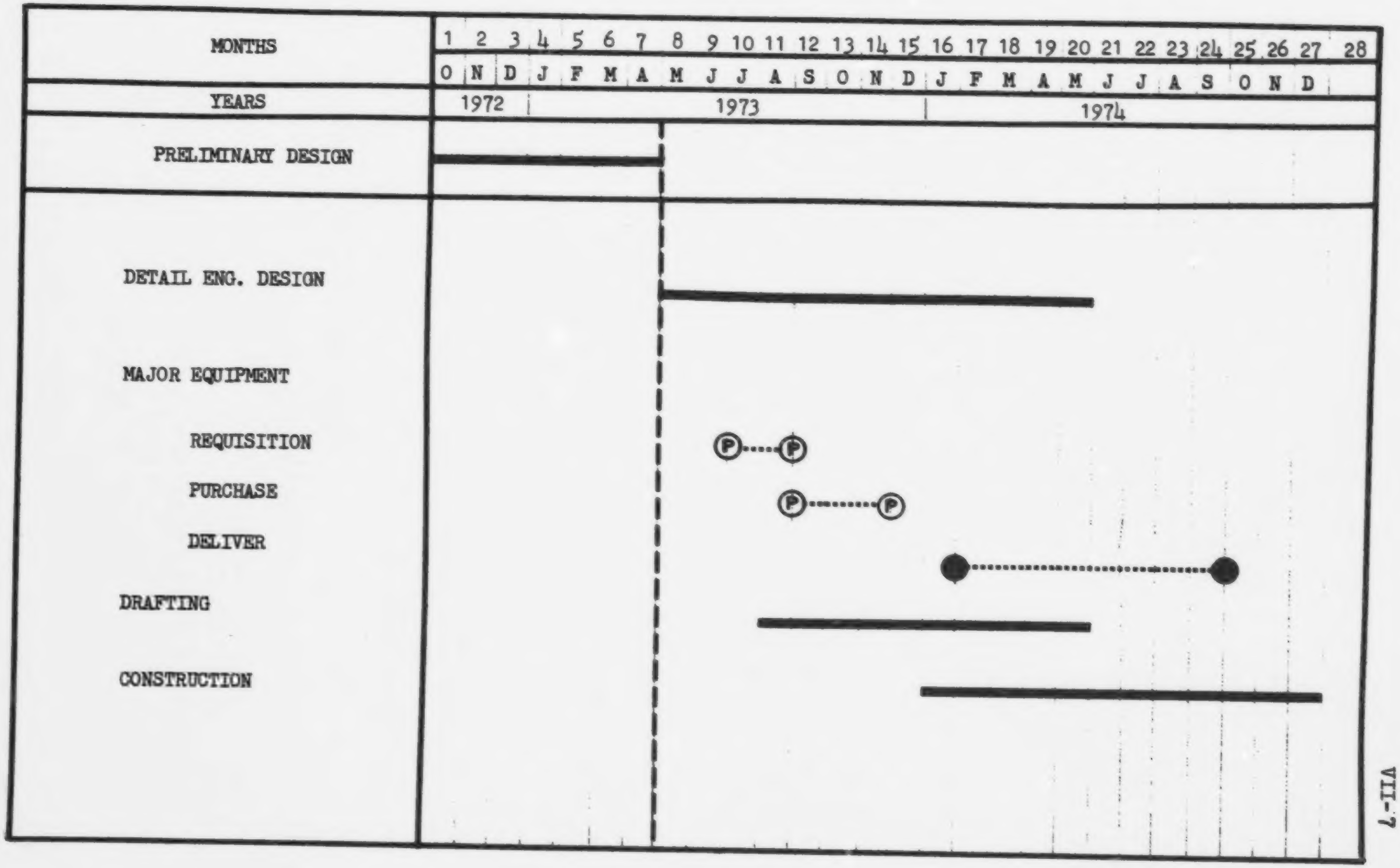
FIGURE X

DESIGN AND CONSTRUCTION SCHEDULE



VII. PLANT CONSTRUCTION AND OPERATION (continued)

5. Cost Estimate and Economics (continued)

Case	Coal Capacity lbs/hr	Boiler Pressure psig	Comp. C-2,C-4	Plant Cost Delivered & Erected
I	22,000	170	omit	$ 9,730,000
II	33,000	320	omit	13,640,000
III	33,000	320	include	16,420,000
IV	33,000	320	omit	16,390,000

An alternate case was considered when the developmental plant is located at an independent site some distance from any power plant. This alternate adds $2,750,000 to either Case II or Case III to cover additional equipment such as water treatment, condensers, boiler feed pumpts, etc. required at our independent site.

The total program cost considering a three-year operation with Case I (A-1 Material Balance) installation amounts to $17,024,000. The total program with a Case II (A-3 Material Balance) installation for a five-year period, including long-term experimental projects amounts to $29,515,000. Details are presented in Table X. It has been assumed that no credit can be taken for intermittent steam generation.

Tables XI and XII present the working capital required and the operation manpower requirements. Tables XIII-A, XIII-B and XIII-C present a breakdown of the cost estimates for Case II. Details of the estimates may be found in Appendix I.

TABLE X

CAPITAL REQUIREMENTS FOR DEVELOPMENTAL BOILER

	Case I (3 years)	Case II (5 years)
A. Capital		
1. Fixed Capital Investment	$ 9,730,000	$13,640,000
2. Working Capital	595,000	816,000
	$10,325,000	$14,456,000
B. Operations		
1. Labor @ $12,000/yr (3)	$1,940,000	$ 3,240,000
2. Utilities (1) (2)	2,448,000	5,490,000
3. Coal & Dolomite (1) (2)	2,030,000	5,100,000
4. Maintenance (@ 3%/yr)	876,000	2,045,000
Operating Cost	$7,294,000	$15,895,000
Total Cash Requirement	17,619,000	30,331,000
Less return of working capital	595,000	816,000
TOTAL COST OF PROJECT	$17,024,000	$29,515,000

NOTES:

(1) Assumes on-stream factor of 50% at normal rate.

(2) Unit cost of utilities, coal & dolomite on next page.

(3) Yearly rate includes fringe benefits and administration.

TABLE No. XI

WORKING CAPITAL

	CASE I	CASE II
1. One Month Inventory		
a) Coal @ $6/T (1)	$48,000	$ 72,000
b) Dolomite @ $5/T (1)	65,000	98,000
2. One Month Wages plus Administration		
54 men @ $12,000/yr (2)	54,000	54,000
3. Utilities (A-1 Case), One Month		
a) Power @ $0.01/kw	119,000	159,000
b) Water @ 10¢/1000 gallons	12,000	17,000
c) Treated Water @ $1/1000 gallons	3,000	4,000
d) Fuel Oil @ $6/bbl	2,000	3,000
4. One Year of Maintenance Equipment @ 3% TFI	292,000	409,000
Total Working Capital	$ 595,000	$ 816,000

NOTES:

(1) Highly dependent on source of material and location of plant site.

(2) Yearly rate includes fringe benefits and general administration.

TABLE NO. XII

MANPOWER REQUIREMENTS

	Men/Shift	Total Men	Total
I. Supervision			
Plant Manager	-	1	
Shift Foremen	1	4	
Maintenance Foreman	-	1	
Chemist & Engineers		3	
Secretary - Clerk		1	
	Sub-total	10	10
II. Operators			
Coal Handling & Preparation (1 shift/D @ 5 days/wk)	-	4	
Dolomite & Coal Injection	1	4	
Compressors	1	4	
Boiler	1	4	
Lock Hoppers & Ash Disposal	1	4	
Utilities	1	4	
Control House	2	8	
	Sub-total	32	32
III. Maintenance			
Instruments	1	4	
Electrical	1	4	
Welder - Boilermaker	1	4	
	Sub-total	12	12
	TOTAL MANPOWER	=	54

TABLE XIII-A

COST ESTIMATE

	CASE II	CASE III
Materials	$6,607,000	$7,763,000
Labor	5,131,000	6,370,000
Const. Insurance	72,000	87,000
Engineering & Fee	1,830,000	2,200,000
	$13,640,000	$16,420,000

TABLE XIIIB
COST ESTIMATE

CASE II
MAJOR EQUIPMENT

ITEM	DESCRIPTION	MATERIAL COST $
R-101	Boiler + Extra Bundles	938,700
D-110	Steam KO Drum	17,600
D-112	Spent Dolomite Lock Hopper	20,900
D-113	" " " "	20,900
D-114	Primary Cyclone Seal Drum	20,600
D-115	" " Lock Hopper	20,900
D-116	Secondary Cyclone Seal Drum	20,600
D-117	" " Lock Hopper	20,900
D-118 A&B	Quench Drum	18,600
D-120	Cyclone Drum	32,300
D-121	Main Air KO Drum	12,000
D-122	" " " "	9,300
D-123	Injection Air KO Drum	3,900
E-101	Main Air Com. Exch.	25,000
E-103	Main Air Comp. Exch.	5,000
RC-101	Dolomite Cooler	60,000
ST-101	Stack	26,000
C-101	Main Air Compressor	940,000
C-103	Injection Air Compressor	155,000
A-101	Instrument Air Compressor	8,100
F-101	Intake Air Filter	8,600
H-102	Peabody Heater	28,700
G-101	First Stage Cyclones (4) + Valves	102,500
G-102	Second Stage Cyclones (4) + Valves	180,500
CR-106	Spent Dolomite Conveyor	20,200
A-102	Purge Air Dryer	10,000
SL-101	Flue Gas Silencer	25,000
	Major Equipment Cost	$2,751,800
	Labor to Erect Equipment	$ 550,000

Form No. 130-135

TABLE XIIIC

COST ESTIMATE

CASE II - TOTAL MATERIALS & LABOR

	MATERIAL COST $	LABOR COST $
Foundations, Paving & Conc. Structures	$ 94,000	$ 142,000
Structural Steel & Pipe Supports	127,000	89,000
Building	28,000	42,000
Piping	412,000	400,000
Instruments	137,000	59,000
Electrical	1,225,000	1,270,000
Insulation	85,000	127,000
Testing	2,200	42,000
Total Other Equipment	$2,110,200	$2,171,000
Process Equipment	2,751,800	550,000
	$4,862,000	$2,721,000
Coal & Dolomite Injection (D&E)	1,745,000	-0-
	$6,607,000	$2,721,000
Field Supervision & Indirect Labor	-	2,410,000
Total Material and Labor	$6,607,000	$5,131,000

APPENDIX I

BASIS OF ESTIMATES

Plant costs presented in Section VII for various cases are based upon equipment quotations, equipment estimates plus standard account factors for piping, instruments and other materials and labor. Factors are obtained by experience on chemical, petroleum and steam generating plants of comparable size and complexity. A set of estimating backup sheets detailing plant costs is included. Equipment items marked "Q" are obtained from vendors quotations, those items marked "E" are estimated equipment. Accounts marked "F" are factored based on experience with comparable plants.

In transforming the estimate from Case II, representing a design at 320 psig boiler casing and 33,000 lbs/hr coal rate to 170 psig and 22,000 lbs/hr coal rate (Case I), the plant cost decreased from $13,640,000 to $9,730,000. Approximately $352,000 of this difference was due to the decrease in pressure and a $3,558,000 decrease was due to the drop in capacity. The influence of capacity on cost was factored for all equipment except the boiler remained the same size only the two smaller steam coils being retained. The influence of pressure on cost was calculated on an item by item basis using such methods as cost per unit weight for pressure vessels to arrive at a plant cost for 170 psig design. These plant costs are indicated in Foster Wheeler Corporation's letter of February 15,1973 to Westinghouse and the costs are detailed on work sheets under Case I.

FOSTER WHEELER CORPORATION

Engineers • Manufacturers • Constructors

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CABLE ADDRESS
REWOP LIVINGSTON NEW JERSEY
TELEPHONE 533-1100
(AREA CODE 201)

February 15, 1973

Mr. E. J. Vidt, Senior Research Scientist
Westinghouse Electric Corporation
Research & Development Center
Beulah Road
Pittsburgh, Pa. 15230

Subject: Pressurized Fluidized Bed
Combustion Boiler
FW 11-52331
Letter No. 47

Dear Mr. Vidt:

Enclosed please find four (4) copies of the revised estimate based upon 2/3 capacity and a reduction of pressure from 350 psig to 170 psig. Equipment sizes, with the exception of the boiler, have been changed to reflect the lower capacity.

The reduction in pressure decreases costs $352,000 from the base case, or 9% of the difference between $13,640,000 and $9,730,000. The change in capacity represents 91% of the above difference or $3,558,000.

Very truly yours,

L. W. Zahnstecher

L. W. Zahnstecher
Process Technology Manager

LWZ/cvm
Enclosures

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AI-3

FOSTER WHEELER CORPORATION, 110 SOUTH ORANGE AVE., LIVINGSTON, N.J.

ESTIMATE SUMMARY

CUSTOMER WESTINGHOUSE RESEARCH LAB

LOCATION PITTSBURGH, PA.

SUBJECT PRESSURIZED FLUIDIZED BED STEAM GENERATION PLANT

NO. 11-52231

DATE 12-11-72 (REV)

PREPARED BY RLS

SHEET NO. 1 OF 4

CODE	RECAP		$M CASE III FUTURE	$M CASE II BASE	$M CASE I 2/3 @170 PSIG	
1000	DIRECT MATERIALS		7527	6400	4751	
2000	SUBCONTRACTS -MAT'L & LABOR		590	518	407	
3000	SUBCONTRACTS -LABOR ONLY		—	—	—	
4000	DIRECT LABOR (MH)		3008	2410	1610	
5000	INDIRECT MATERIALS & TOOLS		—	—	—	
6000	INDIRECT LABOR & SUPERVISION		3008	2410	1610	
7000	PAYROLL BURDEN		—	—	—	
8000	HOME OFFICE (TMH)		—	—	—	
9000	MISCELLANEOUS (INSURANCE)		87	72	52	
	TOTAL COST (ACCTS 1000-9000)		14220	11810	8430	
	ESCALATION -MATERIALS -LABOR -SUBCONTRACTS		NONE	NONE	NONE	
	LABOR PRODUCTIVITY					
	TOTAL EST. COST-ON-BOOKS		14220	11810	8430	
	CONTINGENCY -MATERIALS -LABOR -SUBCONTRACTS		NONE	NONE	NONE	
	CONTRACTOR'S ENGINEERING AND PROCUREMENT COSTS AND FEES FOR GENERAL ADMINISTRATION COSTS AND PROFIT		2195	1823	1297	
	SELLING PRICE (APPROX. ESTIMATE)		16415	13633	9727	
		SAY	16420	13640	9730	

EXCLUDES:- CATALYST, CHEMICALS, TAXES, ROYALTIES.

FORM NO. 130-101

AI-4

ESTIMATE SUMMARY

Client WESTINGHOUSE RESEARCH LAB.
Location PITTSBURGH, PA.
Type Plant PRESSURIZED FLUIDIZED BED
Capacity STEAM GENERATING PLANT
@33,000 lbs/HR COAL & 320 PSIG DESIGN (CASE II)

Classification
Estimate No. 11-52331
Estimate Date 9-27-72
REV Summary Date 12-11-72
Page 2 of 4

Item No.	Qty	Description	Size or Duty	1000 Material Cost $	2/3000 Subcontr. M&L $	4000 Labor Manhours
		Process Equipment				
		COAL PREPARATION	PETROCARB	1,155,000	Q	
		& INJECTION	QUOTE -			
					DELIVERED &	
D-101		WET COAL HOPPER			ERECTED	
D-102		COAL SILO	30'-0"x100'-0" OA		INCLUDING	
					PIPING,	
H-101		AIR HEATER	10'-0"Φ x 20'-0"		INSTRUMENTATION, INSULATION	
					FOUNDATIONS,	
RK-101		COAL DRYER	13'-8" x 55'-10"		ELECTRICAL ETC	
B-101		AIR BLOWER				
B-102		VENT GAS BLOWER				
F-103		BAG FILTER	13'W x 16'H x 30'L			
G-103		PRIMARY CYCLONE	8'-0"Φ x 35'-0" OA			
CR-101		WET COAL CONVEYOR				
CR-102		DRY COAL CONVEYOR				
CR-103		COAL ELEVATOR				
SR-101		COAL CRUSHER	5'W x 6'H x 6'L			
		DOLOMITE INJECTION	PETROCARB	590,000	Q Do	
			QUOTE			
D103		DOLOMITE SURGE DRUM	15'-0"x25'-0" OA			
D104		BLEND. & MIX. SURGE DRUM	7'-0"x16'-0" OA			
D105		LOCK HOPPER	7'-0"x20'-0" OA			
D106		INJECTOR HOPPER	9'-0"x21'-0"			
D107		DOLOMITE RECEIVING HOP.				
D108		DOLOMITE SILO	30'-0"x100'-0" OA			
D109		LOCK HOPPER	7'-0"x14'-0" OA			
D-111		DOLOMITE INJECTOR	9'-0"x26'-0" OA			
CR104		DOLOMITE CONVEYOR				
CR105		DOLOMITE ELEVATOR				
		SUBTOTAL		1,745,000	Q ——	-0-

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AI-5

ESTIMATE SUMMARY

Client WESTINGHOUSE RESEARCH LAB. Classification ______
Location PITTSBURGH, PA. Estimate No. 11-52331
Type Plant PRESSURIZED FLUIDIZED BED Estimate Date 10-1-72
Capacity STEAM GENERATING PLANT REV Survey Date 12-11-72
CASE II Page 3 of 4

Item No.	Qty	Description	Size or Duty	1000 Material Cost $	2/3000 Subcontr. M&L $	4000 Labor Manhours
		Process Equipment				$
		SUBTOTAL PAGE # 1 FORWARD		1,745 000	—	—
R-101	1	FLUIDIZED BED BOILER	12'-6" x 65'-6"	727 600 E		
	(2)	EXTRA BUNDLES		211 100 E		
D-110		STEAM KO DRUM	4'-0" x 16'-0"	✓ 17 600 E		
D-112		SPENT DOLOMITE LOCK HOPPER	6'-6" x 12'-0"	✓ 20 900 E		
D-113		" " " " "	" "	20 900 E		
D-114		PRIMARY CYCLONE SEAL DRUM	"	20 600 E		
D-115		" " LOCK HOPPER	"	20 900 E		
D-116		SECONDARY CYCLONE SEAL DRUM	"	✓ 20 600 E		
D-117		" " LOCK HOPPER	"	✓ 20 900 E		
D-118		QUENCH DRUM	9'-0" x 27'-0"	✓ 18 600 E		
D-119		QUENCH POT	PIPING ITEM	—		
D-120		CYCLONE DRUM	12'-0" x 20'-0"	✓ 32 300 E		
D-121		MAIN AIR KO DRUM	12'-0" x 15'-0"	✓ 12 000 E		
D-122		" " " "	7'-6" x 12'-0"	✓ 9 300 E		
D-123		INJECTION KO DRUM	3'-0" x 12'-0"	✓ 3 900 E		
E-101		MAIN AIR COMPR. EXCH		25 000 E		
E-102		" " " "		DELETED		
E-103		" " " "		5 000 E		
RC-101		DOLOMITE COOLER	7'-8" x 24'-0"	60 000 E		
ST-101		STACK (4" BRICK LINED)	4' & 6' x 100'	✓ 26 000 E		
C-101		MAIN AIR COMPRESSOR	30,000 HP	940 000 Q		
C-102		" " "		DELETED		
C-103		INJECTION AIR COMPRESSOR		155 000 Q		
C-104		EXPANDER		DELETED		
A-101		INST. AIR COMPRESSOR		8 100 Q		
F-101		INTAKE AIR FILTER		8 600 Q		
H-102		PEABODY HEATER		28 700 Q		
G-101	(4)	1ST STAGE CYCLONE (4)		90 000 Q		
G-102		2ND " " "	4'-7" ⌀ x 16'-10"	168 000 Q		
	(8)	TRICKLE VALVES		25 000 Q		
CR-106		SPENT DOLOMITE CONVEYOR	18" WIDE x 200' LG	✓ 20 200 Q		
A102		PURGE AIR DRYER.		10 000 Q		
SL-101		FLUE GAS SILENCER VALVE		25 000 Q		
		TOTAL THIS PAGE	$	2,751,800	$	550 000
		TOTAL PROCESS EQUIPMENT	$	4,496,800	—	—

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ESTIMATE SUMMARY

Client WESTINGHOUSE RESEARCH LAB
Location PITTSBURGH, PA.
Type Plant PRESSURIZED FLUIDIZED BED
Capacity STEAM GENERATING PLANT
CASE II

Classification
Estimate No. 11-52331
Estimate Date 10-4-72
REV ~~Summary~~ Date 12-11-72
Page 4 of 4

Code	Description	Quantity	1000 Material Cost $	2/3000 Subcontr. M&L $	4000 Direct Labor Manhours	 Cost $
	Other Material					
400	Civil Work	—				
410	Earthwork, Dewatering	INCL 430				
421	Piling	NONE				
430	Concrete Foundations	—		137000 F		
440	Roads, Paving, Fencing	—		45000 F		
450	Elevated Concrete Structures	—		54000		
452	Concrete Yard Pipe Supports	NONE				
460	Structural Steel & Platforms	—	82000 F		5800	
465	Steel Yard Pipe Supports	—	45000 F		3100	
470	Buildings	—		70000		
500	Piping (INCL. WATER JACKET)	—	412000 F		40000	
600	Instruments (INCL. ANALYZERS)	—	137000 F		5900	
700	Electrical	—	1225000	—	127000	
810	Insulation - Pipe	—		83000 F		
820	Insulation - Equipment	—		83000 F		
830	Painting	—		46000 F		
840	Fireproofing	NONE				
930	Testing	—	2200	—	4200	
940	Catalysts & Chemicals	NONE				
950	Maintenance Equipment	NONE				
960	Fire Protection Equip.	NONE				
970	Spare Parts	NONE				
990	Other Misc. Equip.	NONE				
	Total Other Material		1903200	518000	186000	1860000
	Total Process Equipment		4496800	—	55000	550000
	Total Direct Matls, Subs. & Labor		6400000	518000	241000	2410000

APPENDIX II

EQUIPMENT SPECIFICATIONS

The following Appendix includes equipment specifications covering:

1. Vessels
2. Coal and Dolomite Receiving and Preparation Systems.
3. Compressors
4. Exchangers
5. Instrumentation and Analyzers
6. Piping
7. Vendors Proposals

A-II. EQUIPMENT SPECIFICATIONS

Equipment List

The following items are included within the scope of the proposed plant.

	Item No.	Service
REACTOR	R-101	Fluidized Bed Boiler
DRUMS	D-101	Wet Coal Hopper
	D-102	Coal Silo
	D-105	Lock Hopper
	D-106	Injector Hopper
	D-107	Dolomite Receiving Hopper
	D-108	Dolomite Silo
	D-109	Lock Hopper
	D-110	Steam Separator
	D-111	Dolomite Injector
	D-112	Spent Sorbent Lock Hopper
	D-113	Spent Sorbent Lock Hopper
	D-114	Primary Cyclone Seal Drum
	D-115	Primary Cyclone Lock Hopper
	D-117	Secondary Cyclone Lock Hopper
	D-118A	Quench Drum
	D-118B	Quench Drum
	D-120	Cyclone Drum
	D-121	Main Air K.O. Drum
	D-123	Injection K.O. Drum

A-II. EQUIPMENT SPECIFICATIONS (continued)

	Item No.	Service
TANK	TK-101	Fuel Oil Storage Tank
EXCHANGERS	E-101	Compressor Air Cooler
	E-103	Compressor Air Cooler
HEATERS	H-101	Air Heater
	H-102	Air Preheater
ROTARY COOLER	RC-101	Spent Dolomite Cooler
KILN	RK-101	Coal Dryer
COMPRESSORS	C-101	Main Air Compressor
	C-103	Injection Air Compressor
PUMPS	P-101 A&B	Fuel Oil Pumps
BLOWERS	B-101	Air Blower
	B-102	Vent Gas Blower
FILTERS	F-101	Intake Air Filter
	F-102	Bag Filter
CYCLONES	G-101	First Stage Cyclones
	G-102	Second Stage Cyclones
	G-103	Primary Cyclone
MATERIAL CONVEYING EQUIPMENT	CR-101	Wet Coal Conveyor
	CR-102	Dry Coal Conveyor
	CR-103	Coal Elevator
	CR-104	Dolomite Conveyor
	CR-105	Dolomite Elevator
	CR-106	Spent Dolomite Conveyor

A-II. EQUIPMENT SPECIFICATIONS (continued)

	Item No.	Service
MISCELLANEOUS	A-101	Instrument Air Compressor & Dryer
	A-102	Purge Air Dryer
	SL-101	Flue Gas Silencer
	SR-101	Coal Crusher
	ST-101	Stack
		Control House
		Compressor House
		Rail Unloading Shed
		Coal Injection Shed
FUTURE	A-201	Water Treater
	C-102	Main Air Compressor
	C-104	Turbine Expander
	D-122	Main Air K.O. Drum
	E-102	Compressor Air Cooler
	E-201	Steam Condensers
	FT-201	Cooling Towers
	P-201	Booster Pumps
	P-202	BFW Pumps
	P-203	Cooling Water Pumps
	P-204	Injection Water Pumps
	TK-201	BFW Storage Tank

A-II. EQUIPMENT SPECIFICATIONS (continued)

Vessels

Pressure vessels and atmospheric drums are included in this section on the basis of the specifications noted on the following drawings and as given below:

Item No.	Service	Drawing No.
D-110	Steam Separator	OP-724-852A
D-112	Spent Sorbent Lock Hopper	OP-724-849A
D-113	Spent Sorbent Lock Hopper	OP-724-849A
D-114	Primary Cyclone Seal Drum	OP-724-850A
D-115	Primary Cyclone Lock Hopper	OP-724-851A
D-117	Secondary Cyclone Lock Hopper	OP-724-851A
D-118 A&B	Quench Drum	OP-724-853A
D-120	Cyclone Drum	OP-724-898&899
D-121	Main Air K.O. Drum	OP-724-854
D-123	Injection K.O. Drum	OP-724-860A

All pressure vessels shall be designed, constructed, inspected and tested in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, latest revision and all applicable addenda. Drums which will operate at atmospheric pressure shall generally adhere to the requirements of the code, but actual construction shall be in accordance with what is referred to as "Good Commercial Practice."

A-II. EQUIPMENT SPECIFICATIONS (continued)

The dual layer linings required for some of the vessels shall consist of a lightweight insulating castable adjacent to the vessel wall to give the desired reduction in temperature and a covering layer of dense refractory castable to protect the insulating layer. Both linings shall be gunned in place, if possible, and shall be supported by anchors welded to the vessel shell. Casting or trowelling of the lining, will be allowed if access prevents the gunning operation from being employed. The lining shall be installed in the vessel fabricator's shop. The curing and drying of the lining installation shall also be performed in the shop prior to shipment of the vessels to the job.

The lining thickness requirements are specified on the vessel drawings. The materials shall be as follows, or the equivalent thereof:

Insulating Castable -	AP Green Light Weight Castable VSL-50 as manufactured by AP Green Refractories Co.
Refractory Castable -	Lo - Abrade as manufactured by AP Green Refractories Co.

ITEM NO. OM-101 Coal Preparation Unit

QUANTITY: One (1)

PURPOSE: To dry and crush coal to proper size range.

DESCRIPTION:

Wet coal will be received from an existing hopper at a size of 1½" x 0". The coal is elevated, dried and crushed.

Supplier's equipment starts at the elevator after the existing feed hopper. Supplier's equipment at the injection system.

SPECIFICATIONS:

1. Capacity - 120,000 lbs/hr of wet coal.
2. Maximum moisture- assume 10% by wt.
3. Coal type - Ohio Pittsburgh No. 8 (see table of properties).
4. Operation - one shift of 8 hrs. per day for five days per week at design capacity. For operation at maximum capacity of 50% over design (180,000 lbs/hr) assume operation for two shifts per day for five days per week.
5. Duty:
    - a) To dry coal from 10% by wt. to 3% by wt.
    - b) To crush coal from 1½" x 0" with minimum fines below 500 microns.
6. Turndown required - none. (Operates 40 hours per week)
7. Materials - suitable for size and type of coal indicated.
8. Location - equipment will be located outdoors in Midwestern USA.

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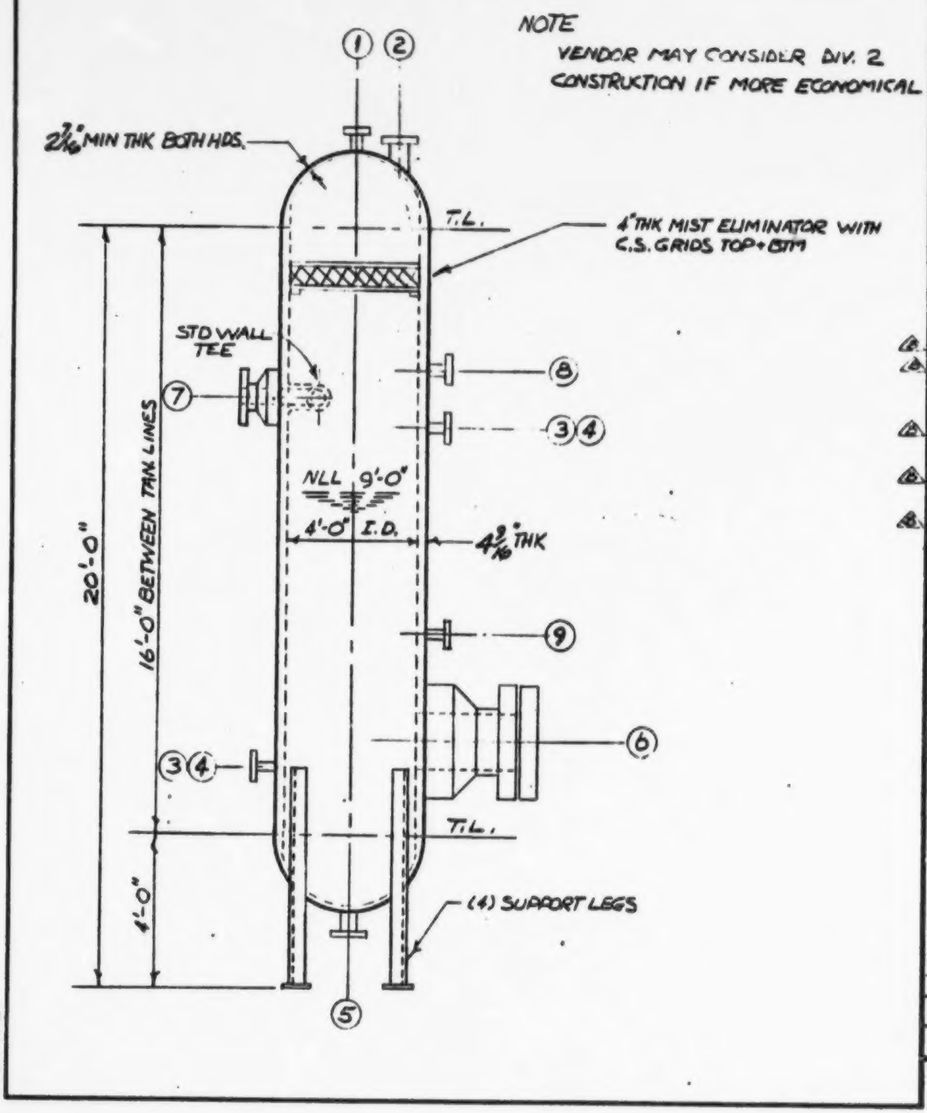


NOTE

VENDOR MAY CONSIDER DIV. 2 CONSTRUCTION IF MORE ECONOMICAL

RELEASES

DWG. REV.	DATE	ISSUED FOR
OP	DATE OF ORDER	Ⓐ PURCHASE SHELL AND HEAD MATERIAL. PREPARE BUT DO NOT SUBMIT SHOP DETAIL DRAWINGS.
		Ⓑ ISSUE CHECKED FOSTER WHEELER DRAWING. PURCHASE ALL OTHER MATERIALS. FINALIZE AND SUBMIT CHECKED SHOP DETAIL DRAWING WITHIN ONE WEEK OF RELEASE DATE. PROCEED WITH COMPLETE FABRICATION.
		Ⓒ VENDOR'S DRAWING RETURNED
		Ⓓ FIELD CONSTRUCTION
		Ⓔ

NOZZLE CHART

	CONN. NO.	SIZE	USAS. RATING	SERVICE	NO. REQD
△B	1	8"	2500#RTJ	STEAM OUTLET	1
△B	2	8"	↓	PSV	2
	3	1½"		LRC	2
	4	1½"		LG	2
△B	5	6"		WATER OUTLET	1
	6	18"		MANWAY W/DAVIT	1
△B	7	6"		INLET	1
	8	1½"		PI	1
△B	9	1"	↓	TR	1

VESSEL DATA A-II-6-a

1	ITEM NO: D-110 NO. REQ'D: ONE
2	SERVICE: STEAM SEPARATOR
3	
4	DIAMETER: 4'-0" I.D.
5	TANGENT LENGTH: 16'-0"
6	OPER. PRESSURE: NORM.: 2400 PSIG
7	(ABOVE LIQUID LEVEL, MAX.: 2500 PSIG
8	DESIGN PRESSURE: 2750 PSIG
9	OPER. LIQUID HOLD-UP PRESS: 3 PSIG
10	OPER. PRESS. DROP THRU VESSEL: — PSI
11	MAX. RELIEVING PRESS. @ TOP HD.: PSI
12	MAX. OPER. TEMPERATURE: 665 °F
13	DESIGN TEMPERATURE: 700 °F
14	SPECIFIC GRAVITY (PROCESS FLUID): 0.56
15	CODE: A.S.M.E. SECT VIII DIV. 1 STAMPED: YES
16	P.W.H.T.: FOR CODE: YES FOR PROCESS: NO
17	RADIOGRAPHED: FULL
18	JOINT EFFICIENCY: 100%
19	CORROSION ALLOWANCE: SHELLS: 1/8" HEADS: 1/8"
20	MATL., SHELL: SA-516, GR 70
21	MATL., HEADS: SA-516 GR 70
22	MATL., SUPPORTS: SA 36
23	TYPE OF HEADS: HEMISPHERICAL
24	EXTERNAL BOLTING: SA193-B7 / SA194-2H
25	INTERNAL BOLTING: —
26	GASKETS: 1/16" THK COMPR. ASBESTOS
27	BOLT HOLES: STRADDLE VESSEL CENTERLINE
28	PAINT: NO
29	INSULATION: YES - 2" THK (BY OTHERS)
30	SHIPMENT: ONE PIECE
31	
32	EMPTY WGT.: 47,000 LBS
33	WATER WGT.: (ONLY) 14,700 LBS
34	TRAYS WGT.: — LBS
35	INSULATION WGT.: 2160 LBS
36	GUNITE WGT.: — LBS
37	OPER. LIQUID WGT.: 4550 LBS
38	
39	
40	
41	HYDROTEST: SHOP: FIELD: PSI
42	GAGE LOCATION:
43	MAX. ALLOW. PRESS. (NEW & COLD): PSI
44	LIMITED BY:
45	

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS

Figure VI-a

REVISIONS

REV.	DATE	BY	DESCRIPTION
B	12-13-72	KL	REV. SIZE NOZZS 1,2,5,7. ADD NOZZ. 9
A	11-1-72	KL	REVISED CORR. ALLOW. & THICK.

DRAWN	JTK	9-18-72
CHECKED		
APP'VED		

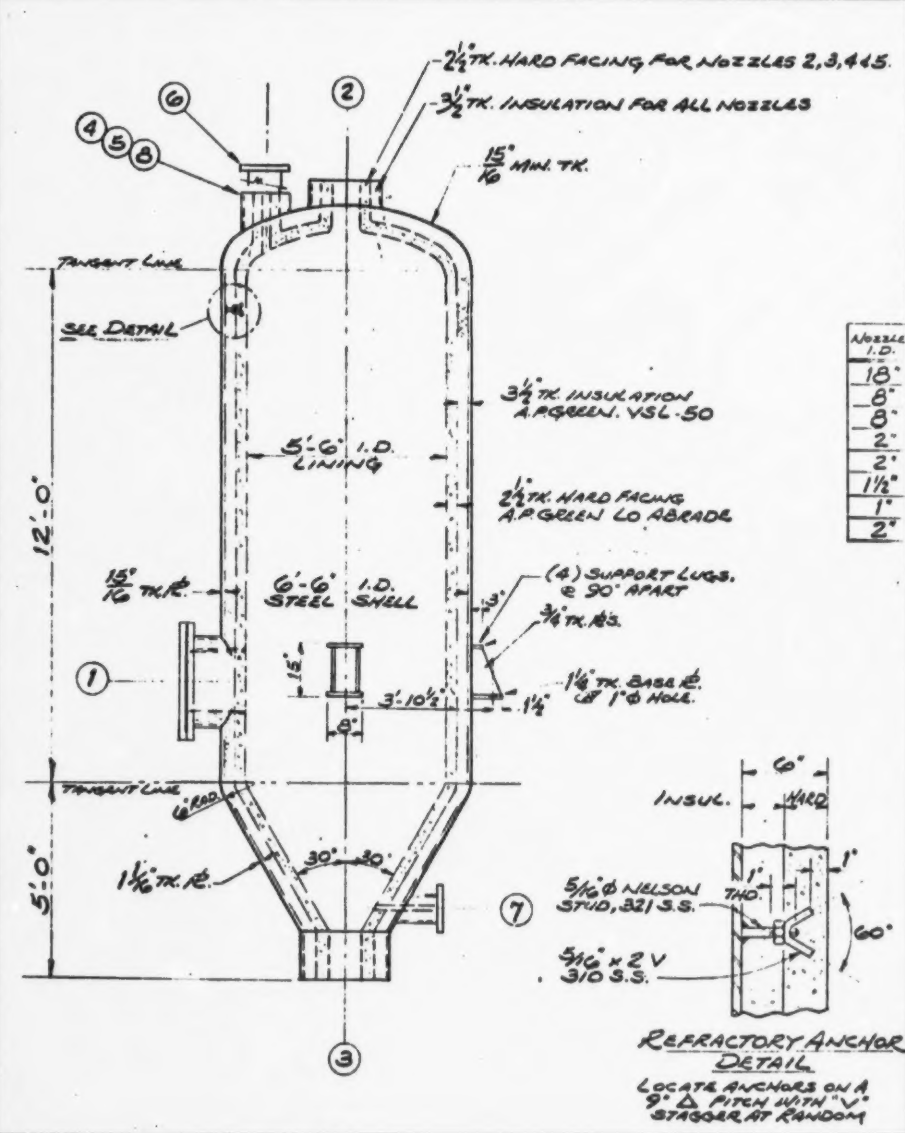
CONTRACT NO: 11-52331

REQUISITION NO:

DRAWING NO: OP-724-852-B

STEAM SEPARATOR D-110
WESTINGHOUSE RESEARCH LABORATORIES
PRESSURIZED FLUIDIZED BED COMBUSTION BOILER

A-II-6-b


2½" TK. HARD FACING FOR NOZZLES 2,3,4 & 5.
3½" TK. INSULATION FOR ALL NOZZLES
15/16" MIN. TK.
⑥
④⑤⑧
②
TANGENT LINE
SEE DETAIL
3½" TK. INSULATION A.P.GREEN. VSL-50
5'-6" I.D. LINING
2½" TK. HARD FACING A.P.GREEN LO ABRADE
12'-0"
15/16" TK. R.
6'-6" I.D. STEEL SHELL
(4) SUPPORT LUGS. @ 90° APART
3"
¾" TK. RS.
①
15"
8"
3'-10½"
1¼" TK. BASE PL. W/ 1"Φ HOLE.
1½"
TANGENT LINE
6" RAD.
5'-0"
1 1/16" TK. R.
30°
30°
⑦
③
INSUL.
6"
HARD
1"
1"
THD.
60°
5/16"Φ NELSON STUD, 321 S.S.
5/16" × 2 V 310 S.S.

REFRACTORY ANCHOR DETAIL

LOCATE ANCHORS ON A 9" Δ PITCH WITH "V" STAGGER AT RANDOM

RELEASES		
DWG. REV.	DATE	ISSUED FOR
OP	DATE OF ORDER	Ⓐ PURCHASE SHELL AND HEAD MATERIAL. PREPARE BUT DO NOT SUBMIT SHOP DETAIL DRAWINGS.
		Ⓑ ISSUE CHECKED FOSTER WHEELER DRAWING. PURCHASE ALL OTHER MATERIALS, FINALIZE AND SUBMIT CHECKED SHOP DETAIL DRAWING WITHIN ONE WEEK OF RELEASE DATE. PROCEED WITH COMPLETE FABRICATION.
		Ⓒ VENDOR'S DRAWING RETURNED
		Ⓓ FIELD CONSTRUCTION
		Ⓔ

		1.D. STUD ENDER	NOZZLE CHART		
NOZZLE I.D.	CONN. NO.	FLANGE SIZE	USAS. RATING	SERVICE	NO. REQD
18"	1	24"	300# RF	MANWAY W/DAVIT	1
8"	2	20"	STUB END	SORBENT INLET	1
8"	3	20"	"	SORBENT OUTLET	1
2"	4	14"	"	BALANCE	1
2"	5	14"	"	PSV	1
1½"	6	8"	300# RF	LR	1
1"	7	6"	"	AERATION CONN.	3
2"	8	14"	STUB END	VENT	1

42 #/CU.FT.
150 #/CU.FT.

VESSEL DATA A-II-6-c	
1	ITEM NO: D-112 & D-113 NO. REQ'D: TWO
2	SERVICE: SPENT SORBENT LOCK
3	HOPPER
4	DIAMETER: INSIDE 6'-6"
5	TANGENT LENGTH: 12'-0"
6	OPER. PRESSURE: NORM.: 170 PSIG
7	(ABOVE LIQUID LEVEL) MAX.: PSIG
8	DESIGN PRESSURE: 320 PSIG
9	OPER. LIQUID HOLD-UP PRESS: PSI
10	OPER. PRESS. DROP THRU VESSEL: PSI
11	MAX. RELIEVING PRESS. @ TOP HD.: PSI
12	MAX. OPER. TEMPERATURE: INTERNAL 1750°-2000°
13	DESIGN TEMPERATURE: SHELL 650°F
14	SPECIFIC GRAVITY (PROCESS FLUID): —
15	CODE: ASME, SECT. VIII DIV. I; STAMPED: YES
16	P.W.H.T.: FOR CODE: NO FOR PROCESS: NO
17	RADIOGRAPHED: SPOT
18	JOINT EFFICIENCY: 85%
19	CORROSION ALLOWANCE: SHELLS: 1/16" HEADS: 1/16"
20	MATL., SHELL: SA-516, GR. 70
21	MATL., HEADS: " " "
22	MATL., SUPPORTS: SA-283, GR. C
23	TYPE OF HEADS: 2:1 ELLIPT. TOP & CONE BTM.
24	EXTERNAL BOLTING: SA-193, B7 & SA-194, 2H
25	INTERNAL BOLTING: NONE
26	GASKETS: SPIRAL WOUND, STYLE CG
27	BOLT HOLES: STRADDLE VESSEL CENTERLINE
28	PAINT: YES - ALUM. (MOBIL 37F-2 OR EQUAL)
29	INSULATION: NONE
30	SHIPMENT: ONE PIECE
31	
32	EMPTY WGT. (STEEL ONLY) 20,000 LBS
33	WATER WGT.: (ONLY) 30,500 LBS
34	TRAYS WGT.: — LBS
35	INSULATION WGT.: — LBS
36	GUNITE WGT.: — LBS
37	OPER. LIQUID WGT.: — LBS
38	INTER. INSULATION WT. 3300 LBS
39	INTER. HARD FACING WT. 10,250 LBS
40	
41	HYDROTEST: SHOP: FIELD: PSI
42	GAGE LOCATION:
43	MAX. ALLOW. PRESS. (NEW & COLD): PSI
44	LIMITED BY:
45	

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS

Figure VI-b

REV.	DATE	BY	DESCRIPTION
B	12-18-72	KL	REVISED NOZZLE CONSTRUCTION
A	11-1-72	KL	REVISED DESIGN PRESS. & THICKS

REVISIONS

DRAWN	KL	9-13-72
CHECKED		
APP'VED		

CONTRACT NO: 11-52331

REQUISITION NO:

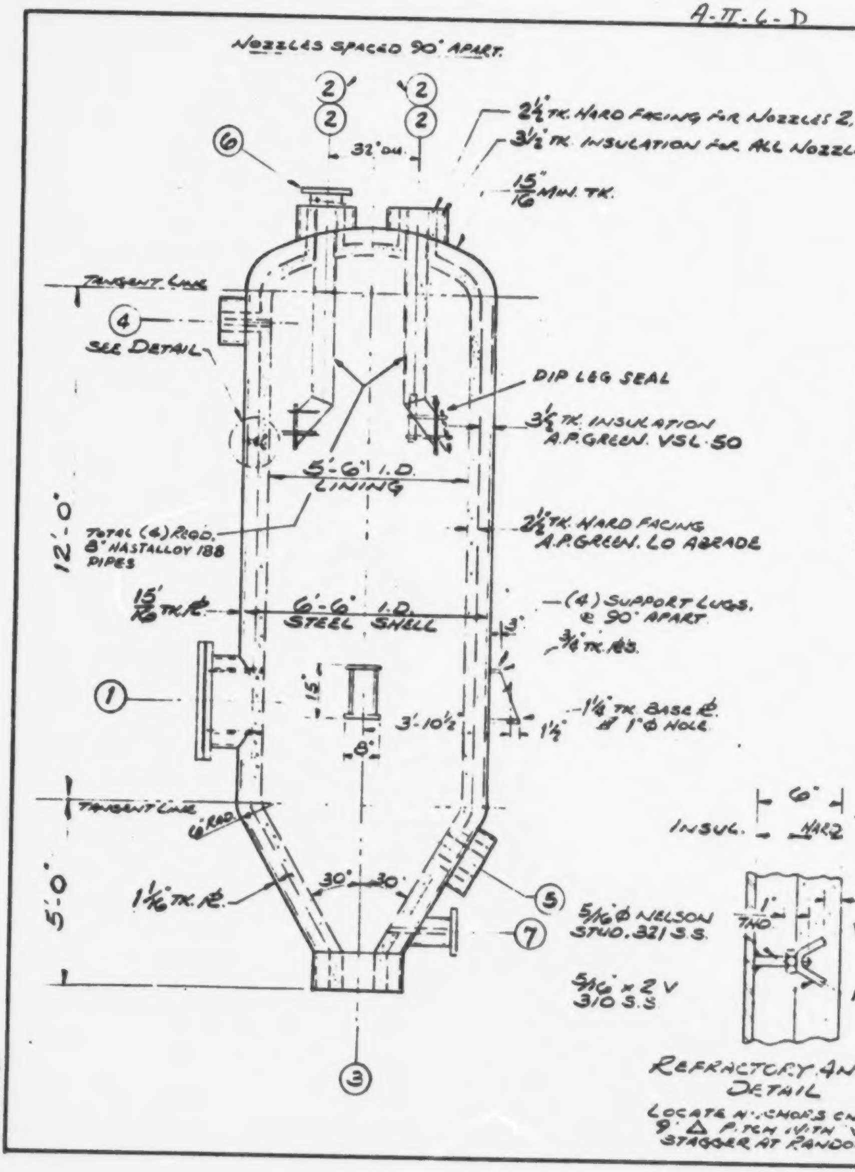
SPENT SORBENT LOCK HOPPER D-112 & D-113
WESTINGHOUSE RESEARCH LABORATORIES
PRESSURIZED FLUIDIZED BED COMBUSTION BOILER

DRAWING NO: OP-724-849-B

44-511 17457

5

A-II-6-D


NOZZLES SPACED 90° APART.
②
②
②
②
⑥
32" DIA.
2½" TK. HARD FACING FOR NOZZLES 2, 3, 4 & 5
3½" TK. INSULATION FOR ALL NOZZLES.
15/16" MIN. TK.
TANGENT LINE
④
SEE DETAIL
DIP LEG SEAL
3½" TK. INSULATION A.P. GREEN. VSL-50
5'-6" I.D. LINING
12'-0"
TOTAL (4) REQD. 8" HASTALLOY 188 PIPES
2½" TK. HARD FACING A.P. GREEN. LO ABRADE
15/16" TK. ℞
6'-6" I.D. STEEL SHELL
(4) SUPPORT LUGS. @ 90° APART
3"
¾" TK. ℞S.
①
15"
3'-10½"
8"
1¼" TK. BASE ℞. W/ 1" Φ HOLE
1½"
TANGENT LINE
6" RAD.
5'-0"
1 1/16" TK. ℞.
30°
30°
⑤
⑦
③
6"
INSUL.
HARD
5/16" Φ NELSON STUD. 321 S.S.
5/16" × 2 V 310 S.S.
1"
1"
THD.
60°
REFRACTORY ANCHOR DETAIL
LOCATE ANCHORS ON A 9" △ PITCH WITH "V" STAGGER AT RANDOM

RELEASES

DWG. REV.	DATE	ISSUED FOR
CP	DATE OF ORDER	Ⓐ PURCHASE SHELL AND HEAD MATERIAL. PREPARE BUT DO NOT SUBMIT SHOP DETAIL DRAWINGS.
		Ⓑ ISSUE CHECKED FOSTER WHEELER DRAWING. PURCHASE ALL OTHER MATERIALS. FINALIZE AND SUBMIT CHECKED SHOP DETAIL DRAWING WITHIN ONE WEEK OF RELEASE DATE. PROCEED WITH COMPLETE FABRICATION.
		Ⓒ VENDOR'S DRAWING RETURNED
		Ⓓ FIELD CONSTRUCTION
		Ⓔ

NOZZLE CHART

NOZZLE I.D.	CONN. NO.	FLANGE SIZE I.D. STUB END	USAS. RATING	SERVICE	NO. REQD
18"	1	24"	300# RF	MANWAY W/DAVIT	1
8"	2	20"	STUB END	DUST INLET	4
8"	3	20"	"	DUST OUTLET	1
2"	4	14"	"	BALANCE .	1
8	5	20"	"	PSV	1
1½"	6	8"	300# RF	LR	1
1"	7	6"	"	AERATION CONN	3

VESSEL DATA

A-II-6-e

1	ITEM NO: D-114 NO. REQ'D: ONE
2	SERVICE: PRIMARY CYCLONE SEAL DRUM
3	
4	DIAMETER: INSIDE 6'-6"
5	TANGENT LENGTH: 12'-0"
6	OPER. PRESSURE: NORM.: 155 PSIG
7	ABOVE LIQUID LEVEL MAX.: PSIG
8	DESIGN PRESSURE: 320 PSIG
9	OPER. LIQUID HOLD-UP PRESS: PSI
10	OPER. PRESS. DROP THRU VESSEL: PSI
11	MAX. RELIEVING PRESS. @ TOP HD.: PSI
12	MAX. OPER. TEMPERATURE: INTERNAL 1600° 2000°
13	DESIGN TEMPERATURE: SHELL 650 F
14	SPECIFIC GRAVITY (PROCESS FLUID): —
15	CODE: ASME, SECT VIII DIV. ; STAMPED: YES
16	P.W.H.T.: FOR CODE: NO FOR PROCESS: NO
17	RADIOGRAPHED: SPOT
18	JOINT EFFICIENCY: 85%
19	CORROSION ALLOWANCE: SHELLS: 1/16" HEADS: 1/16"
20	MATL., SHELL: SA-516, GR. 70
21	MATL., HEADS: " " " .
22	MATL., SUPPORTS: SA-283, GR. C
23	TYPE OF HEADS: 2:1 ELLIPT TOP & CONE BTM
24	EXTERNAL BOLTING: SA-193, B7 & SA-194, 2H
25	INTERNAL BOLTING: NONE
26	GASKETS: SPIRAL WOUND, STYLE CG
27	BOLT HOLES: STRADDLE VESSEL CENTERLINE
28	PAINT: YES - ALUM. (MOBIL 37-F-2 OR EQUAL)
29	INSULATION: • NONE
30	SHIPMENT: ONE PIECE
31	
32	EMPTY WGT.: (STEEL ONLY) 20,000 LBS
33	WATER WGT.: (ONLY) 30,500 LBS
34	TRAYS WGT.: — LBS
35	INSULATION WGT.: — LBS
36	GUNITE WGT.: — LBS
37	OPER. LIQUID WGT.: — LBS
38	INTER. INSULATION WT 3300 LBS
39	INTER. HARD FACING WT. 10,250 LBS
40	
41	HYDROTEST: SHOP: FIELD: PSI
42	GAGE LOCATION:
43	MAX. ALLOW. PRESS. (NEW & COLD): PSI
44	LIMITED BY:
45	

42 #/CU. FT.
150 #/CU. FT.

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS

Figure VI-c

REVISIONS

REV.	DATE	BY	DESCRIPTION
B	12-13-72	KL	REVISED NOZZLE CONSTRUCTION
A	10-31-72	KL	REVISED DESIGN PRESS. & THICK'S

DRAWN	KL	9-3-72
CHECKED		
APP'VED		

PRIMARY CYCLONE SEAL DRUM ITEM D-114

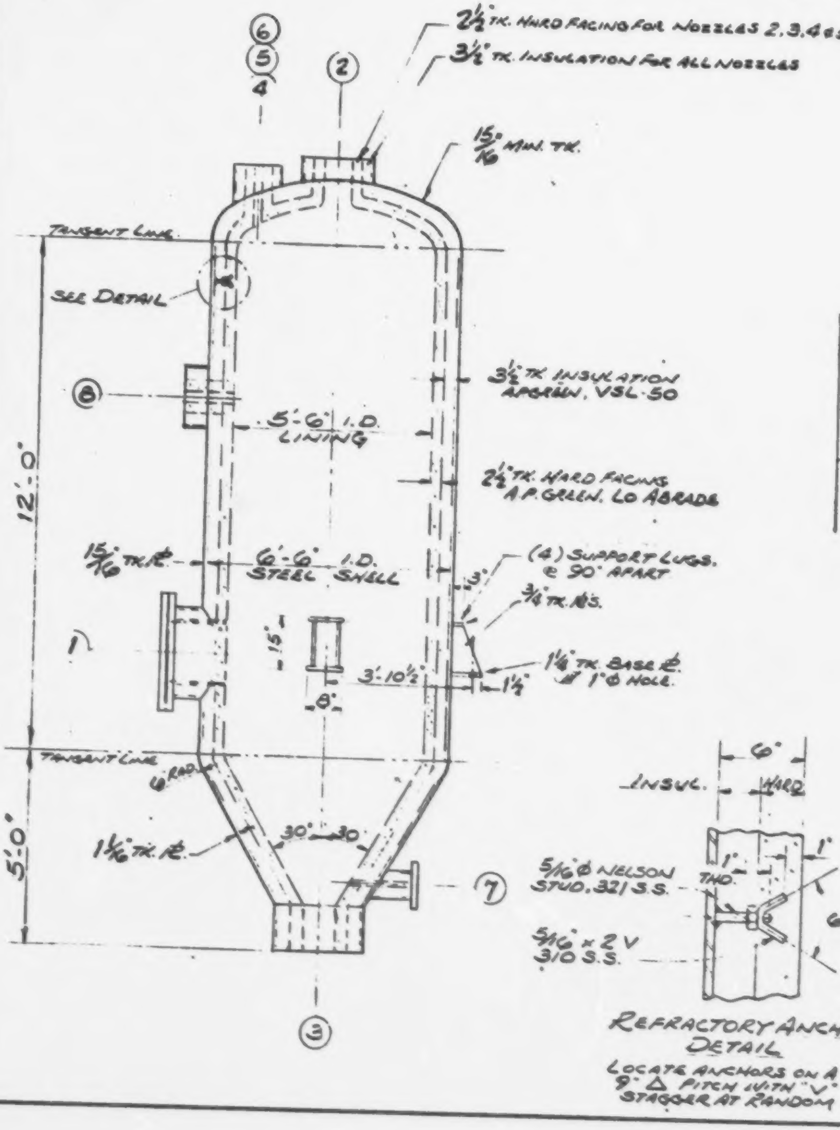
WESTINGHOUSE RESEARCH LABORATORIES
PRESSURIZED FLUIDIZED BED COMBUSTION BOILER

CONTRACT NO: 11-52331

REQUISITION NO:

DRAWING NO: OP-724-850-B

A II-6-F


2½" TK. HARD FACING FOR NOZZLES 2,3,4 & 5
3½" TK. INSULATION FOR ALL NOZZLES
⑥
⑤
4
②
15/16" MIN. TK.
TANGENT LINE
SEE DETAIL
⑧
3½" TK INSULATION APGREEN, VSL-50
5'-6" I.D. LINING
2½" TK. HARD FACING A.P. GREEN, LO ABRADE
12'-0"
15/16" TK. ℞
6'-6" I.D. STEEL SHELL
(4) SUPPORT LUGS. @ 90° APART
3"
3/4" TK. ℞S.
15"
3'-10½"
1¼" TK. BASE ℞. W/ 1"Φ HOLE.
1½"
8"
TANGENT LINE
6" RAD.
5'-0"
1 1/16" TK. ℞.
30°
30
⑦
③
6"
INSUL.
HARD
1"
1"
THD.
5/16"Φ NELSON STUD. 321 S.S.
5/16" × 2 V 310 S.S.
60°

REFRACTORY ANCHOR DETAIL

LOCATE ANCHORS ON A 9" △ PITCH WITH "V" STAGGER AT RANDOM

RELEASES

DWG. REV.	DATE	ISSUED FOR
OP	DATE OF ORDER	Ⓐ PURCHASE SHELL AND HEAD MATERIAL. PREPARE BUT DO NOT SUBMIT SHOP DETAIL DRAWINGS.
		Ⓑ ISSUE CHECKED FOSTER WHEELER DRAWING. PURCHASE ALL OTHER MATERIALS. FINALIZE AND SUBMIT CHECKED SHOP DETAIL DRAWING WITHIN ONE WEEK OF RELEASE DATE. PROCEED WITH COMPLETE FABRICATION.
		Ⓒ VENDOR'S DRAWING RETURNED
		Ⓓ FIELD CONSTRUCTION
		Ⓔ

NOZZLE CHART

NOZZLE I.D.	CONN. NO.	12 STUB END GAGE SIZE	USAS. RATING	SERVICE	NO. REQD
18"	1	24"	300#RF	MANWAY W/DAVIT	1
8"	2	20"	STUB END	DUST INLET	1
8"	3	20"	"	DUST OUTLET	1
2"	4	14"	"	BALANCE	1
2"	5	14"	"	PSV	1
1½"	6	8"	300#RF	LR	1
1"	7	6"	"	AERATION CONN	3
2"	8	14"	STUB END	VENT	1

VESSEL DATA A-II-6-g

1	ITEM NO: D-115 & D-117 NO. REQ'D: TWO
2	SERVICE: PRIMARY CYCLONE LOCK HOPPER
3	SECONDARY CYCLONE LOCK HOPPER
4	DIAMETER: INSIDE 6'-6"
5	TANGENT LENGTH: 12'-0"
6	OPER. PRESSURE: NORM.: 155 PSIG
7	ABOVE LIQUID LEVEL MAX.: PSIG
8	DESIGN PRESSURE: 320 PSIG
9	OPER. LIQUID HOLD-UP PRESS: PSI
10	OPER. PRESS. DROP THRU VESSEL: PSI
11	MAX. RELIEVING PRESS. @ TOP HD.: PSI
12	MAX. OPER. TEMPERATURE: INTERNAL 1600° 2000°
13	DESIGN TEMPERATURE: SHELL 650°F
14	SPECIFIC GRAVITY (PROCESS FLUID): —
15	CODE: ASME, SECT. VIII DIV. 1 STAMPED: YES
16	P.W.H.T.: FOR CODE: NO FOR PROCESS: NO
17	RADIOGRAPHED: SPOT
18	JOINT EFFICIENCY: 85%
19	CORROSION ALLOWANCE: SHELLS: 1/16" HEADS: 1/16"
20	MATL., SHELL: SA-516, GR. 70
21	MATL., HEADS: " " "
22	MATL., SUPPORTS: SA-283, GR. C
23	TYPE OF HEADS: 2:1 ELLIPT TOP & CONE BTM
24	EXTERNAL BOLTING: SA-193, B7 & SA-194, 2H
25	INTERNAL BOLTING: NONE
26	GASKETS: SPIRAL WOUND, STYLE CG
27	BOLT HOLES: STRADDLE VESSEL CENTERLINE
28	PAINT: YES - ALUM. (MOBIL 37-F-2 OR EQUAL)
29	INSULATION: NONE
30	SHIPMENT: ONE PIECE
31	
32	EMPTY WGT. (STEEL ONLY) 20,000 LBS
33	WATER WGT.: (ONLY) 30,500 LBS
34	TRAYS WGT.: — LBS
35	INSULATION WGT.: — LBS
36	GUNITE WGT.: — LBS
37	OPER. LIQUID WGT.: — LBS
38	INTER. INSULATION WT. 3300 LBS
39	INTER. HARD FACING WT. 10,250 LBS
40	
41	HYDROTEST: SHOP: FIELD: PSI
42	GAGE LOCATION:
43	MAX. ALLOW. PRESS. (NEW & COLD): PSI
44	LIMITED BY:
45	

42 #/CU. FT.
150 #/CU. FT.

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS

Figure VI-d

REVISIONS

REV.	DATE	BY	DESCRIPTION
B	12-13-72	KL	REVISED NOZZLE CONSTRUCTION
A	11-1-72	KL	REVISED DESIGN PRESS. & THICK'S.

DRAWN	KL	9-13-72
CHECKED		
APP'VED		

CONTRACT NO: 11-52331

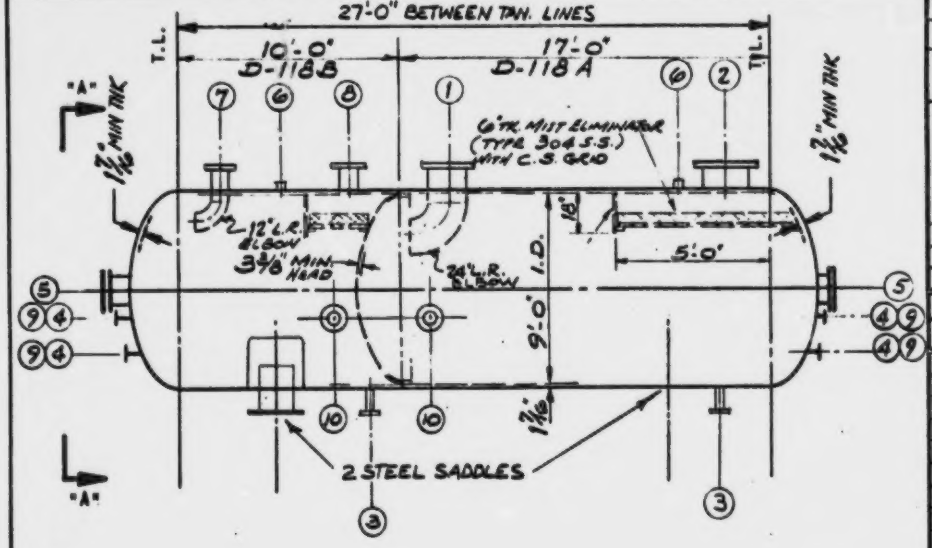
REQUISITION NO:

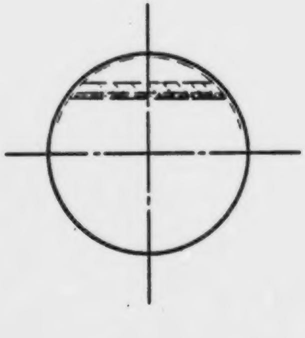
DRAWING NO: OP-724-851-B

PRIMARY CYCLONE LOCK HOPPER ITEM D-115
SECONDARY CYCLONE LOCK HOPPER ITEM D-117
WESTINGHOUSE RESEARCH LABORATORIES
PRESSURIZED FLUIDIZED BED COMBUSTION BOILER

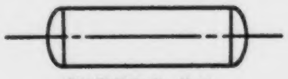
44-511 17457

A-II-6-H





VIEW "A-A"



ORIENTATION PLAN

RELEASES		
DWG. REV.	DATE	ISSUED FOR
OP	DATE OF ORDER	Ⓐ PURCHASE SHELL AND HEAD MATERIAL. PREPARE BUT DO NOT SUBMIT SHOP DETAIL DRAWINGS.
		Ⓑ ISSUE CHECKED FOSTER WHEELER DRAWING. PURCHASE ALL OTHER MATERIALS, FINALIZE AND SUBMIT CHECKED SHOP DETAIL DRAWING WITHIN ONE WEEK OF RELEASE DATE. PROCEED WITH COMPLETE FABRICATION.
		Ⓒ VENDOR'S DRAWING RETURNED
		Ⓓ FIELD CONSTRUCTION
		Ⓔ

NOZZLE CHART

CONN. NO.	SIZE	USAS. RATING	SERVICE	NO. REQD
1	24"	300#RF	VAPOR INLET	1
2	24"		VAPOR OUTLET	1
3	1½"		LIQUID DRAWOFF	2
4	2"		LC	4
5	18"		MANWAY W/DAVIT	2
6	1"	6000#CPLG	P.I.	2
7	12"	300#RF	VAPOR INLET	1
8	12"	"	VAPOR OUTLET	1
9	1½"	"	LG	4
10	4"	"	LSH, LAH	2

REV.	DATE	BY	DESCRIPTION
B	11-15-72	KL	ADD INTER HEAD & NOTES 7,8,9,10
A	11-1-72	KL	REVISED DESIGN PRESS. & THICK'S C.A.

REVISIONS

VESSEL DATA

1	ITEM NO: D-118A&B NO. REQ'D: ONE	
2	SERVICE: QUENCH DRUM	
3		
4	DIAMETER: 9'-0" I.D.	
5	TANGENT LENGTH: 27'-0"	
6	OPER. PRESSURE: NORM.: 150	PSIG
7	(ABOVE LIQUID LEVEL) MAX.: —	PSIG
8	DESIGN PRESSURE: 320	PSIG
9	OPER. LIQUID HOLD-UP PRESS: —	PSI
10	OPER. PRESS. DROP THRU VESSEL: —	PSI
11	MAX. RELIEVING PRESS. @ TOP HD.:	PSI
12	MAX. OPER. TEMPERATURE: 600°F	
13	DESIGN TEMPERATURE: 650°F	
14	SPECIFIC GRAVITY (PROCESS FLUID):	
15	CODE: ASME SECT VIII DIV 1 STAMPED: YES	
16	P.W.H.T.: FOR CODE: YES FOR PROCESS: NO	
17	RADIOGRAPHED: FULL	
18	JOINT EFFICIENCY: 100%	
19	CORROSION ALLOWANCE: SHELLS: 1/4" HEADS: 1/4"	
20	MATL., SHELL: SA-516 GR 70	
21	MATL., HEADS: SA-516 GR 70	
22	MATL., SUPPORTS: SA-283 GR70	
23	TYPE OF HEADS: 2:1 ELLIPTICAL	
24	EXTERNAL BOLTING: SA193-B7 & SA194-2H	
25	INTERNAL BOLTING: SA-307B	
26	GASKETS: 1/16" THK. COMPR. ASBESTOS	
27	BOLT HOLES: STRADDLE VESSEL CENTERLINE	
28	PAINT: NO	
29	INSULATION: YES - 2" THK (BY OTHERS)	
30	SHIPMENT: ONE PIECE	
31		
32	EMPTY WGT.: 88,000	LBS
33	WATER WGT.: (ONLY) 118,800	LBS
34	TRAYS WGT.: —	LBS
35	INSULATION WGT.: 7,000	LBS
36	GUNITE WGT.: —	LBS
37	OPER. LIQUID WGT.: —	LBS
38		
39		
40		
41	HYDROTEST: SHOP: FIELD:	PSI
42	GAGE LOCATION:	
43	MAX. ALLOW. PRESS. (NEW & COLD):	PSI
44	LIMITED BY:	
45		

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS

Figure VI-e

DRAWN	JTK	9-14-72
CHECKED		
APP'VED		

CONTRACT NO: 11-52331

REQUISITION NO:

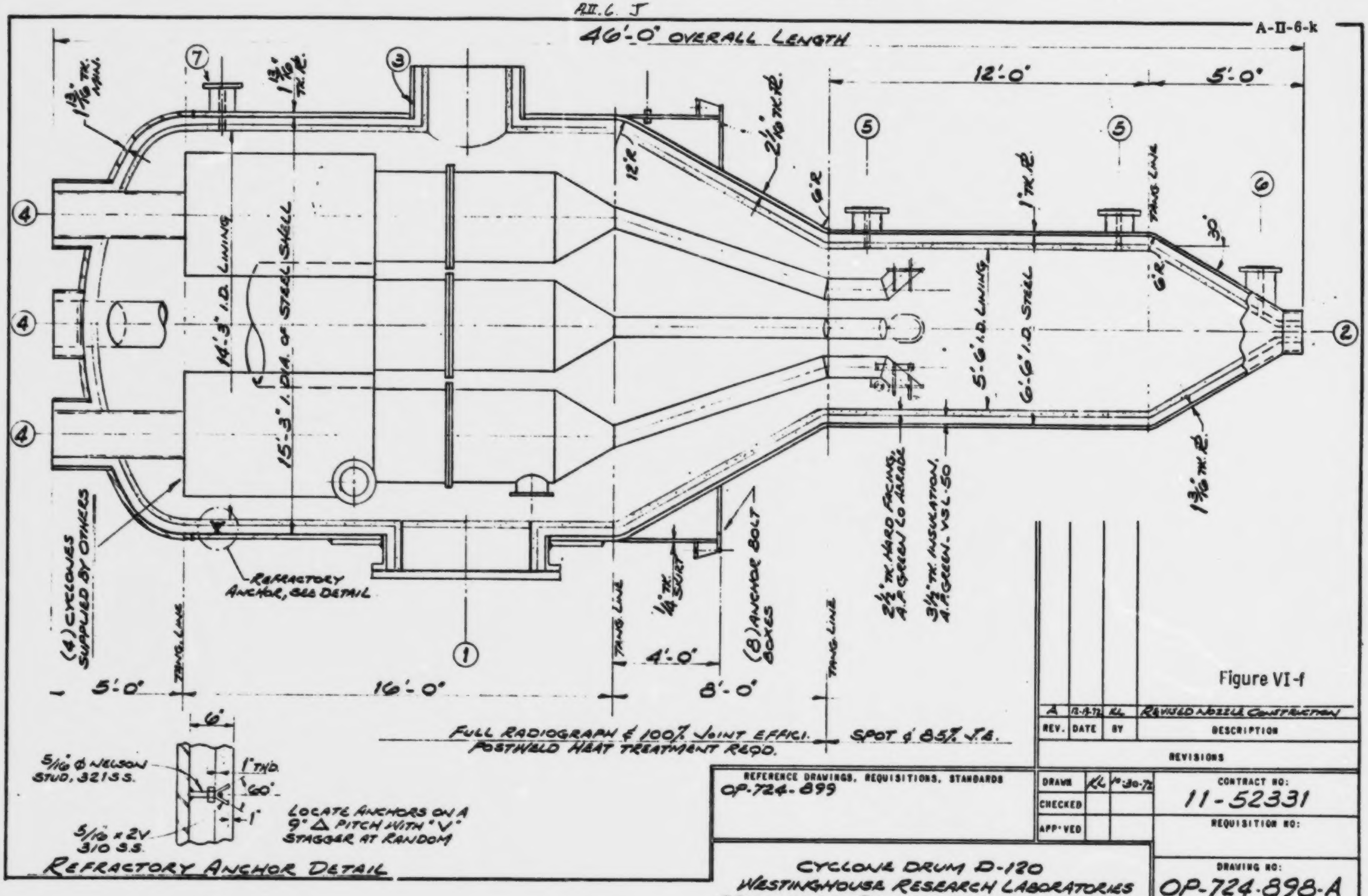
QUENCH DRUM D-118A&B
WESTINGHOUSE RESEARCH LABORATORIES
PRESSURIZED FLUIDIZED BED COMBUSTION BOILER

DRAWING NO: OP-724-853-B

5

A-II-6-k

AII.C. J



REFRACTORY ANCHOR DETAIL

FULL RADIOGRAPH & 100% JOINT EFFICI. — SPOT & 85% J.E.
POSTWELD HEAT TREATMENT REQD.

Figure VI-1

REV.	DATE	BY	DESCRIPTION
A	12-19-72	KL	REVISED NOZZLE CONSTRUCTION

REVISIONS

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS
OP-724-899

DRAWN	KL	10-30-72
CHECKED		
APP'VED		

CONTRACT NO:
11-52331

REQUISITION NO:

CYCLONE DRUM D-120
WESTINGHOUSE RESEARCH LABORATORIES
PRESSURIZED FLUIDIZED BED COMBUSTION BOILER

DRAWING NO:
OP-724-898-A

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RELEASES

DWG. REV.	DATE	ISSUED FOR
OP	DATE OF ORDER	Ⓐ PURCHASE SHELL AND HEAD MATERIAL. PREPARE BUT DO NOT SUBMIT SHOP DETAIL DRAWINGS.
		Ⓑ ISSUE CHECKED FOSTER WHEELER DRAWING. PURCHASE ALL OTHER MATERIALS, FINALIZE AND SUBMIT CHECKED SHOP DETAIL DRAWING WITHIN ONE WEEK OF RELEASE DATE. PROCEED WITH COMPLETE FABRICATION.
		Ⓒ VENDOR'S DRAWING RETURNED
		Ⓓ FIELD CONSTRUCTION
		Ⓔ

NOZZLE CHART

LINING I.D.	CONN. NO.	I.D. STUB END or FLANGE SIZE	USAS. RATING	SERVICE	NO. REQD
60"	1	72"	API-605	MANWAY W/COVER	1
8"	2	20"	STUB END	DUST OUTLET	1
30"	3	42"	"	VAPOR INLET	1
18"	4	25"	"	VAPOR OUTLET	4
1"	5	6"	300# RF	PDI, PDR	2
1"	6	6"	"	AERATION CONN.	3
1"	7	6"	"	P.I.	1

VESSEL DATA

1	ITEM NO: D-120 NO. REQ'D: ONE	
2	SERVICE: CYCLONE DRUM	
3		
4	DIAMETER: (INSIDE STEEL) 15'-3" & 6'-6"	
5	TANGENT LENGTH:	
6	OPER. PRESSURE: NORM.: 155	PSIG
7	(ABOVE LIQUID LEVEL) MAX.:	PSI
8	DESIGN PRESSURE: 320	PSIG
9	OPER. LIQUID HOLD-UP PRESS:	PSI
10	OPER. PRESS. DROP THRU VESSEL:	PSI
11	MAX. RELIEVING PRESS. @ TOP HD.:	PSI
12	MAX. OPER. TEMPERATURE: (INTERNAL) 2000°F	
13	DESIGN TEMPERATURE: (SHELL) 650 °F	
14	SPECIFIC GRAVITY (PROCESS FLUID): —	
15	CODE: ASME, SECT. VIII, DIV. I STAMPED: YES	
16	P.W.H.T.: FOR CODE: YES FOR PROCESS: NO	
17	RADIOGRAPHED: SEE ELEVATION	
18	JOINT EFFICIENCY: " "	
19	CORROSION ALLOWANCE: SHELLS: 1/16" HEADS: 1/16"	
20	MATL., SHELL: SA-516, GR. 70	
21	MATL., HEADS: " " "	
22	MATL., SUPPORTS: SA-283, GR. C	
23	TYPE OF HEADS: 2:1 ELLIPT. TOP & CONE BTM.	
24	EXTERNAL BOLTING: SA-193, B7 & SA-194, 2H	
25	INTERNAL BOLTING: TYPE 321 SS	
26	GASKETS: SPIRAL WOUND, STYLE CG.	
27	BOLT HOLES: STRADDLE VESSEL CENTERLINE	
28	PAINT: YES - ALUM. (MOBIL 37-F-2 OR EQUAL)	
29	INSULATION: NONE	
30	SHIPMENT: TOP, (15'-3"φ) FIELD FABR. AND	
31	(6'-6"φ) ONE PIECE, SHOP FABR.	
32	EMPTY WGT.:	LBS
33	WATER WGT. (ONLY)	LBS
34	TRAYS WGT.: —	LBS
35	INSULATION WGT.: —	LBS
36	GUNITE WGT.:	LBS
37	OPER. LIQUID WGT.: —	LBS
38		
39		
40		
41	HYDROTEST: SHOP: FIELD:	PSI
42	GAGE LOCATION:	
43	MAX. ALLOW. PRESS. (NEW & COLD):	PSI
44	LIMITED BY:	
45		

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS
OP-724-898

Figure VI-g

REV.	DATE	BY	DESCRIPTION
A	12-13-72	KL	REVISED NOZZLE CONSTRUCTION

REVISIONS

DRAWN	KL	10/26/72
CHECKED		
APP'VED		

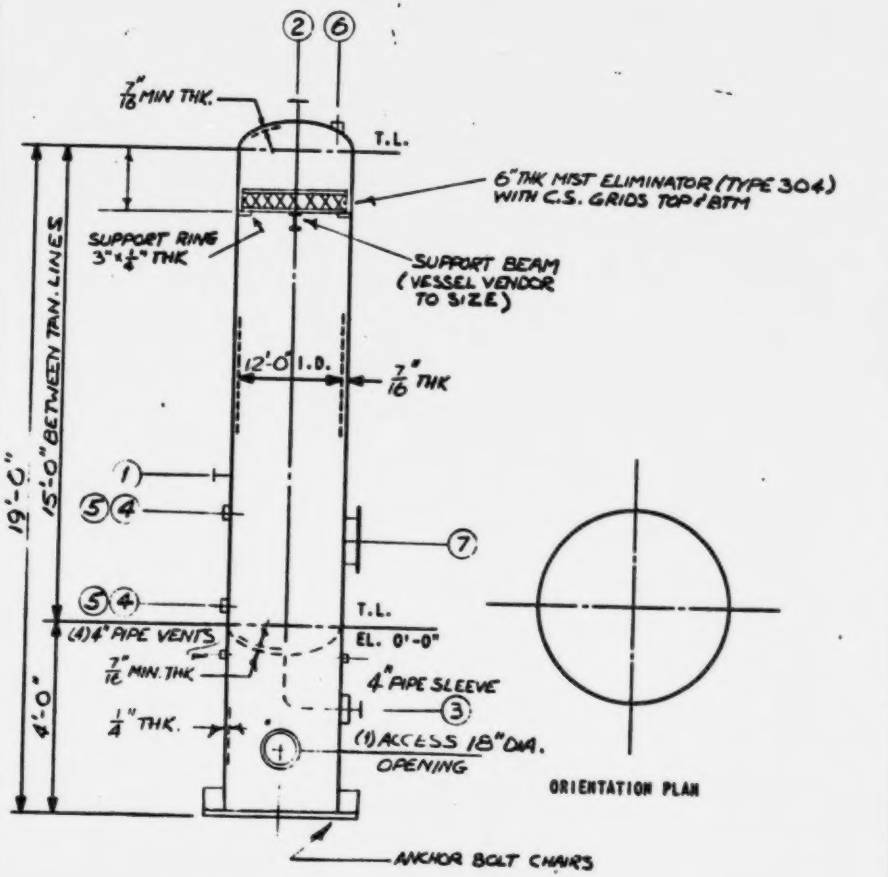
CONTRACT NO:
11-52331

REQUISITION NO:

DRAWING NO:
OP-724-899-A

CYCLONE DRUM D-120
WESTINGHOUSE RESEARCH LABORATORIES
PRESSURIZED FLUIDIZED BED COMBUSTION BOILER

A-II-6-H



RELEASES

DWG. REV.	DATE	ISSUED FOR
OP	DATE OF ORDER	Ⓐ PURCHASE SHELL AND HEAD MATERIAL. PREPARE BUT DO NOT SUBMIT SHOP DETAIL DRAWINGS.
		Ⓑ ISSUE CHECKED FOSTER WHEELER DRAWING. PURCHASE ALL OTHER MATERIALS. FINALIZE AND SUBMIT CHECKED SHOP DETAIL DRAWING WITHIN ONE WEEK OF RELEASE DATE. PROCEED WITH COMPLETE FABRICATION.
		Ⓒ VENDOR'S DRAWING RETURNED
		Ⓓ FIELD CONSTRUCTION
		Ⓔ

NOZZLE CHART

CONN. NO.	SIZE	USAS. RATING	SERVICE	NO. REQD
1	30"	API 605	AIR INLET	1
2	30"	"	AIR OUTLET	1
3	1½"	150 # RF	LIQUID OUTLET	1
4	1"		LG	2
5	1½"		LC	2
6	1"		PI	1
7	18"		MANWAY w/DAVIT	1

VESSEL DATA A-II-6-o

1	ITEM NO: D-721	NO. REQ'D: ONE	
2	SERVICE: MAIN AIR KNOCK		
3	OUT DRUM		
4	DIAMETER: 12'-0" I.D.		
5	TANGENT LENGTH: 15'-0"		
6	OPER. PRESSURE: NORM.:	34.3	PSIG
7	(ABOVE LIQUID LEVEL) MAX.:	34.3	PSIG
8	DESIGN PRESSURE:	60	PSIG
9	OPER. LIQUID HOLD-UP PRESS:	—	PSI
10	OPER. PRESS. DROP THRU VESSEL:	—	PSI
11	MAX. RELIEVING PRESS. @ TOP HD.:	60	PSIG
12	MAX. OPER. TEMPERATURE: 385°F / NORMAL 110°F		
13	DESIGN TEMPERATURE:	435°F	
14	SPECIFIC GRAVITY (PROCESS FLUID):		
15	CODE: A.S.M.E. SECT VIII DIV 1	STAMPED: YES	
16	P.W.H.T.: FOR CODE: NO	FOR PROCESS: NO	
17	RADIOGRAPHED: SPOT		
18	JOINT EFFICIENCY: 85%		
19	CORROSION ALLOWANCE: SHELLS: 1/16"	HEADS: 1/16"	
20	MATL., SHELL: SA-285 GRC		
21	MATL., HEADS: SA-285 GRC		
22	MATL., SUPPORTS: SA-283 GRC		
23	TYPE OF HEADS: 2:1 ELLIPTICAL		
24	EXTERNAL BOLTING: SA193-B7 & SA194-2H		
25	INTERNAL BOLTING: SA-307B		
26	GASKETS: 1/16" THK COMPR. ASBESTOS		
27	BOLT HOLES: STRADDLE VESSEL CENTERLINE		
28	PAINT: YES		
29	INSULATION: NONE		
30	SHIPMENT: ONE PIECE		
31			
32	EMPTY WGT.:	22,800	LBS
33	WATER WGT.: (ONLY)	134,000	LBS
34	TRAYS WGT.:	—	LBS
35	INSULATION WGT.:	—	LBS
36	GUNITE WGT.:	3,760	LBS
37	OPER. LIQUID WGT.:	—	LBS
38			
39			
40			
41	HYDROTEST: SHOP:	FIELD:	PSI
42	GAGE LOCATION:		
43	MAX. ALLOW. PRESS. (NEW & COLD):		PSI
44	LIMITED BY:		
45			

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS

Figure VI-h

REV.	DATE	BY	DESCRIPTION

REVISIONS

DRAWN	JJK	9-12-72
CHECKED		
APP'VED		

CONTRACT NO: 11-52331

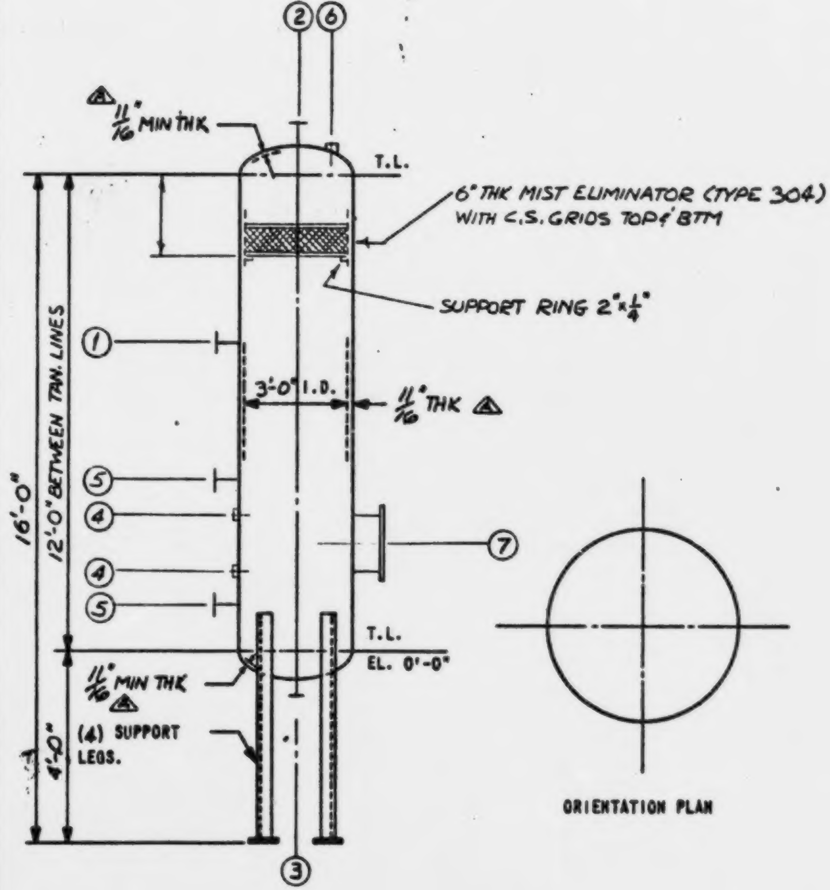
REQUISITION NO:

DRAWING NO: OP-724-854

MAIN AIR KNOCK OUT DRUM D121
WESTINGHOUSE RESEARCH LABORATORIES
PRESSURIZED FLUIDIZED BED COMBUSTION BOILER

5

A-II.6.P



RELEASES

DWG. REV.	DATE	ISSUED FOR
OP	DATE OF ORDER	Ⓐ PURCHASE SHELL AND HEAD MATERIAL. PREPARE BUT DO NOT SUBMIT SHOP DETAIL DRAWINGS.
		Ⓑ ISSUE CHECKED FOSTER WHEELER DRAWING. PURCHASE ALL OTHER MATERIALS. FINALIZE AND SUBMIT CHECKED SHOP DETAIL DRAWING WITHIN ONE WEEK OF RELEASE DATE. PROCEED WITH COMPLETE FABRICATION.
		Ⓒ VENDOR'S DRAWING RETURNED
		Ⓓ FIELD CONSTRUCTION
		Ⓔ

NOZZLE CHART

CONN. NO.	SIZE	USAS. RATING	SERVICE	NO. REQD
1	8"	300#RF	VAPOR INLET	1
2	8"		VAPOR OUTLET	1
3	1½"		LIQUID OUTLET	1
4	1"		LG	2
5	1½"		LC	2
6	1"		PI	1
7	18"		MANWAY W/DAVIT	1

VESSEL DATA A-II-6-q

1	ITEM NO: D-123 NO. REQ'D: ONE		
2	SERVICE: INJECTION AIR KNOCK		
3	OUT DRUM		
4	DIAMETER: 3'-0" I.D.		
5	TANGENT LENGTH: 12'-0"		
6	OPER. PRESSURE: NORM.:	315	PSIG
7	(ABOVE LIQUID LEVEL) MAX.:	—	PSI
8	DESIGN PRESSURE:	347	PSIG
9	OPER. LIQUID HOLD-UP PRESS:	—	PSI
10	OPER. PRESS. DROP THRU VESSEL:	—	PSI
11	MAX. RELIEVING PRESS. @ TOP HD.:	347	PSIG
12	MAX. OPER. TEMPERATURE:	100°F	
13	DESIGN TEMPERATURE:	150°F	
14	SPECIFIC GRAVITY (PROCESS FLUID):	—	
15	CODE: ASME SECT VIII DIV I STAMPED: YES		
16	P.W.H.T.: FOR CODE: NO FOR PROCESS: NO		
17	RADIOGRAPHED: SPOT		
18	JOINT EFFICIENCY: 85%		
19	CORROSION ALLOWANCE: SHELLS: 1/8" HEADS: 1/8"		
20	MATL., SHELL: SA-285 GRC		
21	MATL., HEADS: SA-285 GRC		
22	MATL., SUPPORTS: SA-36		
23	TYPE OF HEADS: 2:1 ELLIPTICAL		
24	EXTERNAL BOLTING: SA193-B7 & SA194-2H		
25	INTERNAL BOLTING: SA-307B		
26	GASKETS: 1/16" THK COMPR. ASBESTOS		
27	BOLT HOLES: STRADDLE VESSEL CENTERLINE		
28	PAINT: YES		
29	INSULATION: NONE		
30	SHIPMENT: ONE PIECE		
31			
32	EMPTY WGT.:	7,000	LBS
33	WATER WGT.: (ONLY)	5,740	LBS
34	TRAYS WGT.:	—	LBS
35	INSULATION WGT.:	—	LBS
36	GUNITE WGT.:	—	LBS
37	OPER. LIQUID WGT.:	—	LBS
38			
39			
40			
41	HYDROTEST: SHOP: FIELD:		PSI
42	GAGE LOCATION:		
43	MAX. ALLOW. PRESS. (NEW & COLD):		PSI
44	LIMITED BY:		
45			

REFERENCE DRAWINGS, REQUISITIONS, STANDARDS

Figure VI-1

REVISIONS

REV.	DATE	BY	DESCRIPTION
A	11-1-72	KL	REVISED CORR. ALLOW. & THICKS.

DRAWN	JTK	9-28-72
CHECKED		
APP'VED		

CONTRACT NO: 11-52331

REQUISITION NO:

INJECTION AIR KNOCK OUT DRUM D-123
WESTINGHOUSE RESEARCH LABORATORIES
PRESSURIZED FLUIDIZED BED COMBUSTION BOILER

DRAWING NO: OP-724-860-A

ITEM NO.: OM-102 Coal injection unit

QUANTITY: One (1)

PURPOSE: Coal is continuously fed into reactor at a uniform controlled rate through multiple feeders.

DESCRIPTION: Dry and crushed coal is pneumatically conveyed from existing storage silos, at a uniform feed rate to a to a Petrocarb, Inc. or equal multiple injection method. The supplier's equipment starts at the storage silos and ends at the reactor.

SPECIFICATION:

1. Capacity - continuous
   Coal - 33,000 lbs/hr max.
2. Coal - ¼" x 0" with 3.3% by wt. moisture
3. Operation - continuous, 3 shifts per day, 7 days per week.
4. Pressure at reactor (receiver for injection)
   - a) Normal - 170 psig
   - b) Design - 320 psig
5. Feed Points
   - a) Four (4) active lines
6. Approximate dimensions for feeder lines about 50 ft. lateral and 40 ft. vertical.
7. Turndown required - to 2,200 lbs/hr (10% of A-1 Case)
8. Materials - suitable for continuous operation with size and characteristics of coal indicated.
9. Location - equipment will be located outdoors in Mid-western USA.

A-II. EQUIPMENT SPECIFICATIONS

2. Coal Preparation Alternate

An alternate quotation was received for a coal crusher and dryer from Williams Patent Crusher and Pulverizer Company, Inc. as a possible replacement for part of the Petrocarb Coal preparation equipment. This proposal is included as well as a comparison of the estimated coal size distribution from Williams and from Petrocarb. It can be seen that the Williams crusher claims a reduction of coal to 0 x 1/4" size with less fines than the Petrocarb system. However, due to the higher cost of the Williams crusher, it was decided to use the Petrocarb system.

WILLIAMS
PATENT CRUSHER and PULVERIZER Co., Inc.
CABLE ADDRESS "CRUSHER-ST.LOUIS"
OLDEST & LARGEST BUILDERS OF HAMMERMILLS IN THE WORLD
CRUSHERS
GRINDERS
SHREDDERS
AIR SEPARATORS
TELEPHONE: AREA CODE 314-621-3348
2701-2723 NORTH BROADWAY
ST. LOUIS, MO., U.S.A. 63102

September 20, 1972

Foster Wheeler Corp.
110 South Orange St.
Livingston, N.J. 07039

Attention: Mr. L. W. Zahnstecher

Subject: Your Ref: FW11-52331
Westinghouse Research Laboratory

Gentlemen:

This is in reply to your September 1st request for a price estimate and information on our coal preparation system.

Williams can provide a complete engineered package system entirely automated, with our patented inert gas system to prevent explosions and fires, and because the entire system is under negative pressure it is clean and dustless.

We understand the system capacity and function is to handle 60 tons per hour of 10% moisture coal, to be crushed from 1½" x o to ¼" x 0 with the moisture reduced to less than 3%.

Based on the coal feed to the system containing 1% or less minus 40 mesh (U.S. Std.) equivalent to 420 microns, the approximate size distribution of the minus ¼" product is as follows:

Sieve Size (U.S. Std.)	Cumulative Percent Passing From Crusher System	From External Screen
1/4"	86.7	100
6 mesh	54.1	62.4
10 mesh	38.4	44.4
40 mesh	13.5	15.6
100 mesh	4.0	4.6
200 mesh	1.4	1.6

From our discussions with Mr. Ed. J. Vidt of Westinghouse we learned they intend to screen the one-pass crushed product and recycle the oversize. This insures an absolute control on 100% passing ¼" top size and avoids over-crushing to result in an absolute minimum of fines as indicated above.

Please refer to page 4 of the enclosed Bulletin No. 856. This illustrates the system we propose to furnish except that item (B) Roller Mill will be replaced by an Impact Mill similar to that shown by figure 1840- page 9 of the enclosed Bulletin No. 723. And item (D) Spinner Separator will be replaced by a Venturi Separator.

Basically the system will consist of the following major components:

(1) Vibratory Feeder with Automatic Feed Control Panel

(2) #5100 Impact Mill with V-Belt Drive and 200 HP Motor

(3) Venturi Separator
(4) Cyclone Collector, heavy duty vacuum type, Rotary Discharge Valve, chain drive and 5 HP gear motor.

(5) Main Fan, heavy duty high static type, with drive and 600 HP Motor. Rated at 74,000 SCFM.

(6) Air Duct for closed circuit Air System, including Inert Gas Duct Circuit.

(7) Air Heater, 25 million BTU capacity per hour, having Automatic Ignition, latest Minneapolis-Honeywell Control Panel as manufactured for Williams Crusher Company utilizing R4138A Flame Safety Programmer and R7161C VersatroniK indicating high temperature limit; Automatic Mill Temperature Control with Partlow Recording Instrument suitable for modulating flame; Controls mounted in a NEMA 12 Panel, wired and piped, shipped as a package including hot air duct to Mill.

(8) Fabric Dust Collector with 11 ounce woven dacron bags complete with reverse jet blowers, factory assembled blow ring carriage, housing braced for 16" water gauge internal static pressure, pre-wired electrical controls for pressure controlled cycling of blow ring carriage; factory assembled complete with V type hopper; screw conveyor, airlock, and drive motor.

(9) Auxiliary Exhaust Fan, heavy duty type with V Belt drive and 250 HP Motor.

Total system price- approximately for estimating $320,000.00

F.O.B. factory.

Shipment approximately 25 weeks.

It is difficult for us to estimate the amount of sulfur released to the atmosphere, but the dust emmission will be practically negligible.

We are represented in your area by Brumitt Associates with Mr. Ron Schmidt at P. O. Box 265, Madison, N.J. 07940 - (201) - 377-2195.

Please let us know how we can be helpful as you proceed.

Yours very truly,

WILLIAMS PATENT CRUSHER & PULVERIZER CO.

J. P. Hensel

J. P. Hensel
Regional Sales Manager

JPH/JS

E-465

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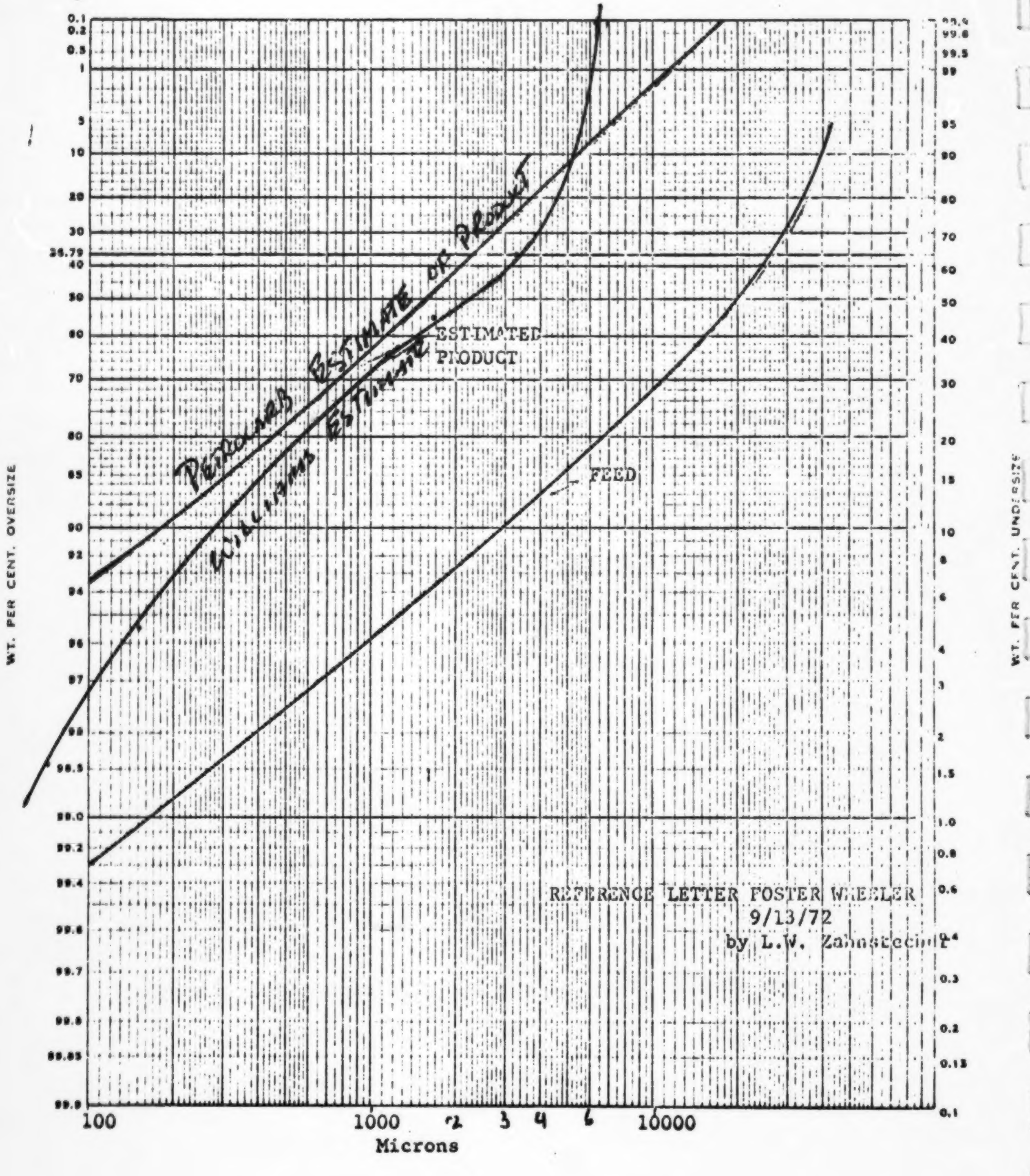
ESTIMATED PARTICLE SIZE DISTRIBUTION
OF
PREPARED COAL



REFERENCE LETTER FOSTER WHEELER
9/13/72
by L.W. Zahnstecher

Petrocarb, Inc.
10/2/72 HR

ITEM: OM-103 dolomite loading and injection system

QUANTITY: One (1)

PURPOSE: To unload fresh dolomite from railroad hopper cars and feeding the dolomite to pressurized reactor through lock hoppers.

DESCRIPTION: Dry and screened dolomite shall be fed from railroad spur track to silo (s) for inventory storage. The dolomite shall then be fed from a live shelf bin to lock hopper. When the lock hopper is full, the unit shall be pressurized and feeding to a injection drum. Dolomite shall then be fed from the injector to the reactor under pressure and at a continuous rate.

SPECIFICATION:

1. Capacity
   - a. Silo(s) - 1800 short tons (approximately two-days inventory).
   - b. Dolomite injector - Dolomite injector shall be sized for feeding the reactor at a maximum rate of 28 ST/Hr at a uniform and continuous rate.

2. Dolomite Feed
   - a. Dried and double-screened 1/4" x 28 mesh
   - b. Bulk density 95 lb/cf.
   - c. Skeletal density - 175 lb/CF

3. Operation
   - a. Silo (s) - silo shall be designed for intermittent operation.
   - b. Feeding the reactor from the lock hoppers must be continuous and uniform in the feeding rate.
   - c. Pollution abatement - dust generated during loading of the silo and lock hoppers shall be recovered.

ITEM NO: OM-103 Dolomite Loading (continued)

SPECIFICATION: 4. Pressure

a. Silo(s)

a. Silo(s)

i) Normal operation - atmospheric on top head.
ii) Design-atmospheric on top head

b. Lock Hopper

i) Normal operation - 170 psig
ii) Design - 320 psig

c. Injector

i) Normal operation - 170 psig
ii) Design - 320 psig

5. Approximate Dimension

a. Railroad hooper cars will be located approximately 300 feet from the silo(s).

b. The dolomite injector will be located 40 feet, laterally, from the silo(s).

c. The dolomite injector will be feeding the reactor at an elevation of 80 feet above the grade.

6. Turndown Required

Required turndown is to 3,573 lbs/hr (10% of A-1 Case)

ITEM NO.: G-101 A, B, C & D First Stage Cyclones

SERVICE: Fluidized Bed Boiler

NO. OF STAGE: One (1)

NO. OF CYCLONES PER STAGE: Four (4)

TYPE OF CYCLONE: Ducan Type 700 VM, size 200 or equal

OPERATING CONDITION:

Cases	A.1	A.2	A.3
No. of Cyclone in Service	3	2	4
Fluid	Flue Gas		
Operating Temperature, °F	1,600	1,600	1,600
Operating Pressure, PSIA	169.7	169.7	169.7
Atmospheric Pressure, psia	14.7	14.7	14.7
Capacity, ACFM	19,750	12,847	27.155
Gas Characteristics (Ex. Dust)			
Density, Lb/CF	0.231	0.230	0.232
Average Mol Wt.	30.16	30.04	30.30
Viscosity, centipoise	0.043		
Dust Loading Grains/CF	28.9	26.7	31.58
Inlet Velocity, fps	54.9	53.5	56.6
Pressure Drop inches W.G.			
Inlet to Outlet	15.7	15.0	16.8
Inlet to Dipleg	22.6	21.6	24.0
Dipleg Diameter	8"		
Cyclone solid emission grains/ACF	3.005	2.789	3.246

Dust Characteristics

Composition

Ash (Fly ash)	60 Wt. %
Dolomite	10 Wt. %
Carbon	30 Wt. %

Particle Size Distribution, grains/CF
(at inlet to cyclone)

Less than 1 micron	0.05
1 to 3 microns	0.479
3 to 5 microns	0.774
5 to 10 microns	2.161
10 to 20 microns	2.242
20 to 50 microns	3.872
50 to 100 microns	5.095
Larger than 100 micron	5.706

ITEM NO.: G-101 A, B, C & D First Stage Cyclones (Cont'd)

Apparent Particle Density gm/ml

Flyash	0.5
Dolomite	2.8
Carbon	1.2

Design Condition

For Internal Installation	
Temperature, F	2,000
Pressure, psi	2
For External Installation	
Temperature, °F	2,000
Pressure, psig	320

Notes:

1. For external installation the exposed surface of the cyclones, shall be kept at 300°F (max.).
2. Dimension insdie of the lined cyclone shall be the same as for the unlined cyclone.

ITEM NO.:	G-102 A, B, C & D Second Stage Cyclones
SERVICE:	Fluidized-Bed Boiler
NO. OF STAGE:	One
NO. OF CYCLONES PER STAGE:	Four
TYPE OF CYCLONES:	Aerodyne Series S Type III Model 4500 or equal

OPERATING CONDITION:

Cases	A.1	A.2	A.3
No. of Cyclone in Service	3	2	4
Fluid	Flue Gas		
Operating Temperature, °F	1600	1600	1600
Operating Pressure, psia.	168.4	168.6	168.1
Atmospheric Pressure, psia	14.7	14.7	14.7
Capacity, ACFM	19879	12,908	27839
Gas Characteristics (Ex. Dust)			
Density, Lb/CF	0.2295	0.2289	0.2301
Average Mol Wt.	30.16	30.04	30.30
Viscosity, centipoise	0.043	0.043	0.043
Dust Loading, Grains/CF	2.896	2.776	3.220
Pressure Drop, Inc. W.G.			
Primary Gas	5.5	5.5	5.5
Secondary Gas	21.0	21.0	21.0
Dip Leg	+2.0	+2.0	+2.0
Cyclone Solid Emission, grains/ACF	0.295	0.274	0.321
Acc. Cyclone efficiency, %	90.1	90.1	90

Dust Characteristics

Composition, wt. %

Ash (Flyash)	60
Dolomite	10
Carbon	30

Case		A.1		A.2		A.3	
Particle Size Distribution							
		Acc. Weight Percent					
Particle Size Less Than		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1.27	Microns	9.62	48.7	9.57	48.5	9.73	48.75
5.55	"	57.55	97.2	57.29	97.2	58.22	97.3
12.40	"	85.03	100.0	84.91	100.0	85.32	100.0
24.89	"	92.58		92.49		92.80	
46.62	"	95.64		95.56		95.84	
77.81	"	96.76		96.69		96.93	
81.67	"	97.29		97.23		97.44	
85.54	"	97.73		97.68		97.85	
89.41	"	98.09		98.05		98.19	
93.27	"	98.37		98.34		98.45	
97.09	"	98.62		98.59		98.70	
100.88	"	98.85		98.83		98.93	
104.59	"	99.06		99.03		99.12	
108.23	"	99.24		99.22		99.29	
111.77	"	99.40		99.38		99.45	

Apparent Particule Density gm/ml

Flyash	0.5
Dolomite	2.8
Carbon	1.2

Design Condition

For Internal Installation	
Temperature, °F	2,000
Pressure, psi	2

ITEM:	C-101 Main Air Compressor
QUANTITY:	One
TYPE:	Multistage Centrifugal
TYPE DRIVE:	Motor

PROCESS PERFORMANCE:

Fluid	Air
Intake Temp., °F	77
Atmospheric Pressure, PSIA	14.7
Intake Pressure, PSIA	14.3
Discharge Pressure, PSIA	185
Desired Discharge Temp., °F	500
Capacity MMSCFD (Dry) (No Neg Tol)	114.4
Moisture Content at Intake, Vol. %	2.1

NOTES:

(1) Intake temperature will vary from -10°F to 95°F. At temperature below design the intake capacity will remain constant.

(2) When Intercoolers are required, allow 5 PSI pressure drop. Air outlet temperature from the coolers 110°F (Min.).

(3) Vendor to provide complete self-contained oil lubricating system.

(4) Air filter and intake silencer will be provided by others.

(5) Buffer seal gas will be made available, if required.

ITEM: C-103 Injection Air Compressor

QUANTITY: One

TYPE: Single Stage Centrifugal

SERVICE:
a. Injection and Pressuring air to Petrocarb Unit
b. Aeration air to hoppers
c. Purge air for instruments

DRIVE: Motor

PROCESS PERFORMANCE:

Fluid	Air
Intake Temp., °F	100
Atmospheric Pressure, PSIA	14.7
Intake Pressure, PSIA	180
Discharge Pressure, PSIA	315
Capacity MMSCFD	17.0
Moisture Content at Intake, Vol.%	Saturated

NOTES:

(1) Compressor casing shall be designed for 465 psia discharge pressure.

(2) Compressor will take suction from Main Air Compressor, C-101.

(3) Vendor to provide complete self-contained oil lubricating system.

ITEM: F-101 Intake Air Filter

QUANTITY: One

SERVICE: Main Air Compressor

PROCESS PERFORMANCE:

Fluid	Air
Intake Temp. °F	-10 to 95
Atmospheric Pressure, psig	14.7
Capacity MMSCFD	114.4
Allowable Pressure Drop across intake line, psi	0.3 max.
Allowable Noise Level dBA	90 max. (1)
Intake Line Size Inches	48 max.

NOTES:

(1) The noise level of the suction line shall be kept at 90 dBA at less at 10 feet from air intake. If necessary, an intake silencer shall be provided.

(2) Total pressure drop of the intake filter and silencer should not exceed 0.3 psi.

(3) The intake air filter shall have weather louvres.

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FOSTER WHEELER CORPORATION

PUMP PROCESS DATA

FORM 110-29

CUSTOMER Westinghouse Research Laboratory

JOB NO. 11-52331

LOCATION Pittsburgh, Pa.

SHEET 1 OF 1

ITEM NO. P-101 A&B

SERVICE Fuel Oil Pump

SPARE ALSO COMMON TO ITEM

REV.	0	1	2	3
DATE				
MADE BY				

PUMP TYPE: ☐ CENTRIF. ☒ RECIP. POWER ☐ RECIP. STEAM ☐ ROTARY ☐ METERING ☐

NUMBER OF PUMPS REQUIRED: Two OPERATING one SPARE one

TYPE OF DRIVER: Motor OPERATING one SPARE one

DUTY: ☐ CONTIN. ☐ INTERMITT .@ APPROX. 2080 HRS/YR.

PROCESS REQUIREMENTS PER PUMP

OPERATING CASE	Design			MINIMUM FLOW CASE	MAXIMUM SP.GR.CASE
LIQUID	No. 2 Fuel Oil				
PUMPING TEMP.: NORMAL °F	130				
EXPECTED MAX. °F	130				
SR.GR. @ P.T.: RATED (MIN.)	0.83				
EXPECTED MIN.					
VAPOR PRESS. @ P.T. PSIA	0.1				
VISCOSITY @ P.T. CKS	2				
CAPACITY @ P.T.: REQUIRED U.S. GPM	7				
NORM. U.S. GPM					
DISCH. PRESS.: REQUIRED PSIG	450				
SUCT. PRESS.: REQUIRED PSIG	0				
(MAX. POSSIBLE) PSIG	(3)	( )	( )	( )	( )
DIFFERENTIAL PRESS. PSI	450				
DIFF. HEAD (CENTRIF. PUMPS ONLY) FT					
NPSH AVAILABLE FT					
CORROSION/EROSION FROM	Nil				
SPECIAL DETAILS					

FLOW CONTROLLED BY ☐ LC ☐ TC ☐ PC ☐ FC ☐ OTHER

METHOD OF STARTING SPARE PUMP: ☐ MANUAL ☐ AUTOMATIC

DRIVER STEAM: INLET

EXHAUST

NOTES:

MATERIALS RECOMMENDED CASING INTERNALS

ITEM: RC-101 Spent Dolomite Cooler

QUANTITY: One (1)

PURPOSE: To cool spend dolomite and fly ash from various look hoppers.

DESCRIPTION: Spend dolomite at elevated temperature and pressure will be fed first to the lock hoopers. Periodically the lock hopper will be depressured discharging the dolomite into the spent dolomite cooler. Partciulate (fly ash) recovered from various cyclones will also be discharged to the appropriate lock hoppers for loading to the same cooler.

SPECIFICATION:

	Spent Dolomite	Fly Ash	Design
Operating Temp., °F (Inlet)	1,750	1,600	-
Operating Pressure	Atm.	Atm.	-
Design Temperature, °F	2,000	2,000	2,000
Design Pressure	Atm.	Atm.	Atm.
Capacity, TPH (Normal)	15.75	2.34	-
Capacity, TPH (Design)	21.3	3.2	24.5
Desired Cooler Outlet Temp., °F	300 (Max.)	300 (Max.)	300 (Max.)
Particle Size			
	¼" x 0		
Less than 20 microns		28 Wt. %	
20-50 microns		19 Wt. %	
50-100 microns		25 Wt. %	
Greater than 100 microns		28 Wt. %	
Particle Bulk Density, Lb/CF	95	31	

NOTES:

1. In order to protect the down stream equipment, the outlet temperature of the spend dolomite cooler must not exceed 300°F at the rated capacity of 24.5 TPH.

2. The cooler shall be designed to handle very fine particles from spent dolomite and/or fly ash.

3. Cooling water to the unit will be available at 85°F and 50 psig. Cooling water return shall be restricted to 120°F.

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A-II-24

FORM NO. 135-120A

MATERIAL REQUISITION

FOSTER WHEELER CORPORATION
110 SOUTH ORANGE AVENUE, LIVINGSTON, N. J.

SHELL & TUBE EXCHANGERS

PAGE 1 OF 1

CONTRACT NO. 11-52331 | REQ'N. NO. | DATE 9/13/72

CUSTOMERS NAME Westinghouse Research Lab. | LOCATION Pittsburgh, Pa.

SUPERSEDED BY

CHANGE NO.	C-1	C-2	C-3	C-4	C-5	C-6
DATE						

SERVICE OF UNIT Compressor Air Cooler ITEM NO. E-101

SIZE 44" x 18'0" TYPE A-J-S (HORIZ) CONNECTED IN -

SQ.FT.SURF./UNIT (EFF) 9700 SHELLS/UNIT one SQ.FT.SURF./SHELL (EFF)

PERFORMANCE OF ONE UNIT

	SHELL SIDE		TUBE SIDE	
FLUID CIRCULATED	Air		Cooling Water	
TOTAL FLUID ENTERING	366.504	LB/HR	977.200	LB/HR
VAPOR	361.666	LB/HR		LB/HR
LIQUID		LB/HR	(1954 GPM) 977.200	LB/HR
STEAM		LB/HR		LB/HR
NON-CONDENSABLES	4838	LB/HR		LB/HR
FLUID (VAPORIZED)(CONDENSED)		LB/HR		LB/HR
STEAM CONDENSED		LB/HR		LB/HR
GRAVITY				
VISCOSITY				
MOLECULAR WEIGHT Vapor Mix	28.6			
SPECIFIC HEAT		BTU/LB-°F		BTU/LB-°F
THERMAL CONDUCTIVITY		BTU/HR-FT-°F		BTU/HR-FT-°F
LATENT HEAT		BTU/LB		BTU/LB
TEMPERATURE IN	385	°F	85	°F
TEMPERATURE OUT	110	°F	110	°F
OPERATING PRESSURE, INLET	35	(PSIG)	50	(PSIG)
NO. PASSES PER SHELL	Divided Flow		Two	
VELOCITY		FT/SEC	5.9	FT/SEC
PRESSURE DROP - ALLOW. | CALC'D.	4.0 PSI	PSI	10.0 PSI	PSI
FOULING RESISTANCE, MIN.	0.002		0.002	

HEAT EXCHANGED - BTU/HR. 24,400,000 MTD CORRECTED-°F 89.6

TRANSFER RATE - SERVICE 28.08 CLEAN

CONSTRUCTION OF ONE SHELL

	SHELL SIDE		TUBE SIDE	
DESIGN PRESSURE	75	PSIG	75	PSIG
TEST PRESSURE	Per Code	PSIG	Per Code	PSIG
DESIGN TEMPERATURE	435	°F	160	°F

TUBES C-STL (3) NO. 1110 O.D. 3/4" BWG 14 (MIN) LENGTH 18'0" PITCH 1"

SHELL C-STL 44" I.D.	SHELL COVER C-STL (REMOV)
CHANNEL C-STL	CHANNEL COVER C-STL
TUBESHEET - STATIONARY C-STL	TUBESHEET - FLOATING C-STL
BAFFLES - CROSS C-STL TYPE DBL SEGM	FLOATING HEAD COVER C-STL
BAFFLES - LONG - TYPE	IMPINGMENT PROTECTION Place Shell Inlet on
TUBE SUPPORTS -	vapor belt - leave K.O. on bottom for
TUBE TO TUBESHEET JOINT Expanded	exiting vapor

GASKETS

CONNECTIONS - SHELL SIDE IN 30" OUT (2) 22" RATING 150 #RF

CONNECTIONS - TUBE SIDE IN 10" OUT 10" RATING 150 #RF

CORROSION ALLOWANCE - SHELL SIDE 1/8 IN. TUBE SIDE 1/8 IN.

CODE REQUIREMENTS ASME VIII-Div. 1 TEMA CLASS B

REMARKS: (1) NOZZLE & SUPPORT LOCATION TO BE AS NOTED ON F.W. STD. 21B11.1
(2) FOR GENERAL NOTES REFER TO REQ'N. WHICH IS AN INTEGRAL PART OF THIS REQ'N
(3) Wolverine finned tube (19 F/I) #60-195065 or equal

FORM NO. 135-128A

A-II-25
SHELL & TUBE
EXCHANGERS
PAGE 1 OF 1

MATERIAL REQUISITION

FOSTER WHEELER CORPORATION

110 SOUTH ORANGE AVENUE, LIVINGSTON, N. J.

CONTRACT NO. 11-52331	REQ'N. NO.		DATE 9/2/72
CUSTOMERS NAME Westinghouse Research Lab.	LOCATION Pittsburg, Pa.		

SUPERSEDED BY

CHANGE NO.	C-1	C-2	C-3	C-4	C-5	C-6
DATE						

SERVICE OF UNIT Comp. Air Cooler ITEM NO. E-103

SIZE 21" x 20'0" TYPE AES CONNECTED IN -

SQ.FT.SURF./UNIT (EFF) 964 SHELLS/UNIT one SQ.FT.SURF./SHELL (EFF) 964

PERFORMANCE OF ONE UNIT

	SHELL SIDE		TUBE SIDE	
FLUID CIRCULATED	Air		C.W.	
TOTAL FLUID ENTERING	40612	LB/HR	274,667	LB/HR
VAPOR		LB/HR		LB/HR
LIQUID		LB/HR	549 GPM	LB/HR
STEAM	536	LB/HR		LB/HR
NON-CONDENSABLES		LB/HR		LB/HR
FLUID (VAPORIZED)(CONDENSED)		LB/HR		LB/HR
STEAM CONDENSED	403	LB/HR		LB/HR
GRAVITY				
VISCOSITY				
MOLECULAR WEIGHT				
SPECIFIC HEAT		BTU/LB-°F		BTU/LB-°F
THERMAL CONDUCTIVITY		BTU/HR-FT-°F		BTU/HR-FT-°F
LATENT HEAT		BTU/LB		BTU/LB
TEMPERATURE IN	500	°F	85	°F
TEMPERATURE OUT	100	°F	100	°F
OPERATING PRESSURE, INLET	170	(PSIG)	50	(PSIG)
NO. PASSES PER SHELL	One		Two	
VELOCITY		FT/SEC		FT/SEC
PRESSURE DROP - ALLOW. | CALC'D.	4 PSI	PSI	6 PSI	PSI
FOULING RESISTANCE, MIN.	0.002		0.002	

HEAT EXCHANGED - BTU/HR. 4,120,000 MTD CORRECTED °F 97.5

TRANSFER RATE - SERVICE 43.8 CLEAN

CONSTRUCTION OF ONE SHELL

	SHELL SIDE		TUBE SIDE	
DESIGN PRESSURE	200	PSIG	75	PSIG
TEST PRESSURE		PSIG		PSIG
DESIGN TEMPERATURE	600	°F	150	°F

TUBES CS NO. 252 O.D. 3/4 BWG 14 LENGTH 20'0" PITCH 1" Sq.

SHELL CS 21" I.D.	SHELL COVER CS (REMOV)
CHANNEL CS	CHANNEL COVER CS
TUBESHEET - STATIONARY CS	TUBESHEET - FLOATING CS
BAFFLES - CROSS CS TYPE SEGM'T	FLOATING HEAD COVER CS
BAFFLES - LONG TYPE	IMPINGMENT PROTECTION Yes

TUBE SUPPORTS

TUBE TO TUBESHEET JOINT Rolled

GASKETS

CONNECTIONS - SHELL SIDE IN 10" OUT 10" RATING 300 # RF

CONNECTIONS - TUBE SIDE IN 6" OUT 6" RATING 150 # RF

CORROSION ALLOWANCE - SHELL SIDE 1/8 IN. TUBE SIDE 1/8 IN.

CODE REQUIREMENTS ASME VIII Div. 1 TEMA CLASS B

REMARKS: (1) NOZZLE & SUPPORT LOCATION TO BE AS NOTED ON F.W. STD. 21811.1
(2) FOR GENERAL NOTES REFER TO REQ'N. WHICH IS AN INTEGRAL PART OF THIS REQ'N

ITEM NO.: A-101 Instrument Air Compressor & Dryer

QUANTITY: One (1)

SPECIFICATION: Complete instrument air package system including air compressor, filter, water trap, dual automatic pressure switch [illegible] dryer and all necessary attenting equipment.

Air capacity, SCFM	70
Ambient Temperature:	95°F
Moisture content of Intake Air	saturated
Dew point of instrument Air	-40°F
Atmospheric Pressure	14.7 psia
Compressor Drive	motor

The instrument air shall be free of foreign matter and dried to -40°F dew point at all time. The instrument air shall be made available at the battery limit at 100 psig and 100°F.

Form No. 110-135

ITEM:	A-102 Package Purge Air Dryer
QUANTITY:	one
SPECIFICATION:	Complete instrument purge air dryer including feed gas cooler, oil filter, dual automatic pressure switch dryer and all necessary attenting equipment.

Air Capacity, SCFM	1,000
Inlet Temperature, °F	200
Inlet Pressure, psia	465
Moisture Content	Sat.
Dew Point of air Required, °F	-40

NOTES:

1. An air cooler shall be provided upstream of the dryer, complete with separator and water trap.
2. The purge air shall be free of foreign matter and dried to-40°F dew point at all times.
3. Cooling water will be available at 85°F and 50 psig. Cooling water outlet temperature should not exceed 120°F.

A-II. EQUIPMENT SPECIFICATIONS (continued)

5. Instrumentation & Analyzers

The purpose of instrumentation is to control the process, to indicate the performance of the unit and to effect safe action in the case of emergency conditions.

Instrumentation shall be as shown on Engineering Flow Diagrams OP-721-423, 424 and 426. Instruments and controls are identified by a system of letters (and numbers) generally in accordance with the Instrument Society of American Standard S5.1 Additional symbols, if used, will be explained by suitable notes on the flow diagrams. Pneumatic transmission shall be utilized; however, provision shall be made for computer data logging.

The instrument panel shall be full graphic, with miniature instruments and a maximum instrument density of 2.5 maximum per lineal foot.

Analyzers shall be provided for measuring the composition of flue gases from the Reactors and the flue gas leaving the Quench Scrubber. Also, the ash from the boiler and the cyclones shall be analyzed to determine the extent of conversion of the coal. The components to be analyzed are listed on the flow diagrams at the required points.

The selection, sizing and design of relief valves or other relieving systems shall be generally in accordance with API Standards, ASME vessel codes, or applicable piping codes.

Instruments and their connections shall be located for maximum convenience in operating and servicing the instruments, and shall be oriented so as to avoid obstruction of aisles and platforms. Control

A-II. EQUIPMENT SPECIFICATIONS (continued)

5. Instrumentation & Analyzers (continued)

valves shall be accessible from grade or platforms. Local pressure gauges, dial thermometers and test wells shall be located so as to be at a visible level, and test points shall be readily accessible. All instruments requiring adjustment must also be accessible for servicing from grade, walkways, ladders or platforms. Accessibility from grade may be from a portable ladder and, for transmitters, from a portable platform.

6. Piping

Piping, the general arrangement of same with respect to equipment and instrumentation, shall be as shown on Engineering Flow Diagrams OP-721-433, OP-721-424 and OP-721-426. As a minimum requirement, the design of piping shall be in accordance with the latest revision of the Code for Pressure Piping, ANSI B31.3.

Materials of construction for pipe lines and equipment are noted on the Engineering Flow Diagrams listed above. To explain the symbolization utilized for each pipe line, the following example is employed:

$$\frac{3'' - 300\# \text{ CS-1}}{(600^\circ\text{F} - \text{HC})}$$

Above the line, in order:

a) Line size (3")

b) Nominal ANSI rating for flanges (300#)

c) Material specification (CS)

d) Corrosion allowance (1)

Below the line, in order:

e) Operating temperature, usually maximum (600°F)

f) Insulation requirement (HC)

A-II. EQUIPMENT SPECIFICATIONS (continued)

6. Piping (continued)

For identification of all symbols on the flow diagrams, the following represent a further breakdown of the symbols:

ANSI Ratings

150# - Equivalent to 150# RF

300# - Equivalent to 300# RF

2500# - Equivalent to 2500# RTJ

2500#+ - Above the requirements of 2500# RTJ. A review of the nominal 2500# rating would be necessary to determine what changes, if any, should be made to existing standard dimensions to make the 2500# RTJ rating suitable for the pressure and temperature conditions.

SPCL. - Special considerations required for piping (see below for further data).

Materials

CS - Carbon Steel

1¼ Cr - 1¼% Chrome, ½% Moly

Corrosion Allowances

1 - Nominal, equal to .05" for carbon steel, .03" for alloy

2 - 1/16"

3 - 1/8"

4 - 1/4"

Insulation Requirements

NI - Not to be insulated

HC - To be insulated for heat conservation

PP - To be insulated only where required for personnel (burn) protection

A-II. EQUIPMENT SPECIFICATIONS (continued)

6. Piping (continued)

The line sizes and operating temperatures as given for each line are self-explanatory.

With reference to the above rating classification designated as "SPCL", this particular classification has been used for pipe lines operating at high internal temperatures. Such lines will require a dual layer lining and should consist of a layer of lightweight insulating castable adjacent to the pipe wall, to give a desired reduction in metal temperature, and a covering layer of dense refractory castable to protect the insulating layer. Both layers must be gunned in place and supported by anchors welded to the pipe wall. Casting or trowelling of the lining is allowed if access prevents gunning.

Recommended materials and thicknesses are as follows:

a) Insulating Castable

VSL-50 as manufactured by A. P. Green Refractories Co. Thickness of layer - 3½".

b) Refractory Castable

Lo-Abrade as manufactured by A. P. Green Refractories Co. Thickness of layer - 2½".

c) Anchors

5/16" diameter Nelson studs, Type 321 stainless steel, welded to pipe wall, with 5/16" diameter refractory clips (see anchor detail on vessel drawings where shell requires similar dual layer lining) and heavy hex nuts, Type 310 stainless steel, attached to stud.

A-II. EQUIPMENT SPECIFICATIONS (continued)

7. Vendors' Proposals

Included in this section are several of the vendors' quotations that were received in connection with requests for price and engineering data for the various equipment items. Wherever the information was useful for further descriptive purposes, it has been made a part of the process and mechanical specifications for the individual items of equipment.

PETROCARB, INC. 250 BROADWAY, NEW YORK, N. Y. 10007

CABLE ADDRESS "CABOCARB" NEW YORK
TELEPHONE (212) 267-8810

November 8, 1972

Foster Wheeler Corporation
110 South Orange Avenue
Livingston, New Jersey 07039

Attention: Mr. L. W. Zahnstecher, Process Technology Manager
Subject: Coal Preparation and Injection System and
Dolomite Injection System (Ref. No. 11-23351)
Petrocarb Projects E-465 and E-467

Gentlemen:

This will confirm our telephone conversation concerning our revision of costs in connection with the subject projects. We have reviewed our estimate of the coal preparation and injection system as well as the dolomite injection system.

The pre-blending of coal and dolomite have been eliminated. The coal will be fed batch-wise from the upper "live shelf" directly into the "storage injector". A special valve will be used to control the batch of coal and will receive its impulse to open by the cycle logic and will close based on an impulse from a special probe in the storage injector.

The revised estimated installed cost of the coal injection system is $425,000.00. The primary advantage of this change is that the live shelf can contain a much greater weight of coal or, if desired, the coal storage silo could be reduced in total volume and height. This is of course dictated by your desired storage volume.

The dolomite bin, steel supports, foundations, and bucket elevator will not be needed since this equipment is being replaced by the dolomite system referred to in our letter of September 6, 1972. This change results in a credit of $70,000.00 which changes the coal preparation system estimated cost to $730,000.00 with a total for coal preparation and injection of $1,155,000.00.

Our earlier estimate of $590,000.00 for the dolomite system is still applicable.

Please let us know if we can be of further service.

Very truly yours,

PETROCARB, INC.

Harold Reintjes

Harold Reintjes
President

HR:jml

cc: Mr. R. W. Bryers
Foster Wheeler Corporation

THE DUCON COMPANY, INC.
147 EAST SECOND STREET · MINEOLA, NEW YORK 11501
TEL: 516 741-6100 · CABLE: DUCON MINEOLANY · TWX 510 222-9861

September 19, 1972

Foster Wheeler Corp.
110 South Orange Ave.
Livingston, New Jersey

Attention: Mr. Chen

Subject: Customer Reference Number FWC 11-52331
Ducon Proposal P72-437

Dear Mr. Chen:

In response to your letter of September 6, 1972, I have enclosed our budgetary estimate for four (4) Ducon VM 700 Size 200 Cyclones along with copies of our Engineering Design Data Sheets (Tables 1-6) outlining expected Cyclone operating results for your conditions.

Design Data For External Installation:

Pressure	320 PSIG
Internal Temperature - Long Time	1600°F
Internal Temperature - Short Time	2000°F
Cyclone Shell Temperature	320°F
ASME Code Stamped	Yes
Joint Efficiency	85%
Minimum Carbon Steel Thickness	7/8"
External Construction Material	Carbon Steel A-515-60
Allowable Stresses For A-515-60	15,000 PSI
Erosion Resistant Castable Thickness	2½"
Insulating Castable Thickness	4"

Ducon Proposal P72-437

The estimated price for four (4) Ducon VM 700 Size 200 Cyclones is

Eighty to Ninty Thousand Dollars.........($80,000 - $90,000)

Our Granular Bed estimate will be forthcoming.

Sincerely,
THE DUCON COMPANY, INC.
D. Buzzelli
D. Buzzelli

DB:aw

A-II-36

DUCON

THE DUCON COMPANY, INC.
147 EAST SECOND STREET · MINEOLA, NEW YORK 11501
TEL. 516 741 [illegible] · CABLE DUCON MINEOLANY · TWX 510 222-[illegible]

October 20, 1972

Foster Wheeler Corporation
110 South Orange Ave.
Livingston, New Jersey 07039

Attention: Mr. C.W. Chen
Process Design Department
Process Plants Division

Subject: Your Reference FWC 11-52331
Ducon Proposal P72-437

Dear Mr. Chen,

In response to your telephone call of October 18, 1972, I am enclosing one (1) copy of each of the revised Engineering Data Sheets, Tables 1, 2 and 3. These tables have been revised according to the conditions you relayed to me during your call.

We hope the enclosed is sufficient for your present needs and should you have any questions, please do not hesitate to contact us.

Very truly yours,
THE DUCON COMPANY, INC.
Dennis Buzzelli
D. Buzzelli

DB:aw

Member

AIR POLLUTION CONTROL EQUIPMENT · PNEUMATIC CONVEYING SYSTEMS

Reproduced from best available copy.

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PROGRAM: BOCY10                           DATE: 10/20/72

                    THE DUCON CO. INC.
                  147 E. SECOND STREET
                  MINEOLA, N.Y. 11501

CUSTOMER: FOSTER WHEELER

CUSTOMER REFERENCE NUMBER: FWC 11-52331

DUCON REFERENCE NUMBER: P72-437

                         TABLE  1

   DUCON CYCLONE OPERATING AND DESIGN DATA SHEET

CYCLONE SELECTION: NO. OF STAGES                  1
TOTAL GAS FLOW                               377998 LBS/HR
TOTAL GAS FLOW AT OPERATING CONDITION         27155 ACFM
OPERATING GAS DENSITY @ COND.                0.2320 LBS/CF
OPERATING VISCOSITY @ COND.                  0.0430 CP
OPERATING GAS TEMPERATURE                      1600 DEG.F.
OPERATING GAS PRESSURE                       169.70 PSIA
PARTICLE DENSITY                               42.0 LBS/CF
OPERATING SOLIDS INLET LOADING                 7355 LBS/HR
OPERATING SOLIDS INLET LOADING                31.60 GRAINS/ACF

CYCLONE STAGES                                FIRST
CYCLONE SIZE                                    200
CYCLONE TYPE                                     VM
CYCLONE MODEL                                   700
NO. OF CYCLONES                                   4
OPERATING GAS FLOW PER CYCLONE                 6789 ACFM
CYCLONE INLET VELOCITY                         56.6 FT/SEC
CYCLONE SALTATION VELOCITY                     23.0 FT/SEC
CYCLONE FRACTIONAL EFFICIENCY CURVE NO.        46.4
CYCLONE OUTLET TO INLET RATIO                  1.50
CYCLONE PRESSURE DROP                          16.8 IN.WG.
CYCLONE DIP-LEG SUCTION                        24.0 IN.WG.
CYCLONE DIP-LEG DIAMETER                          8 IN.
DIP-LEG SOLIDS RATE                            1.31 LBS/SEC-SQ.FT.
CYCLONE SOLIDS LOSS RATE                     755.57 LBS/HR
CYCLONE SOLIDS EMISSION                       3.246 GR/ACF
ACC. CYCLONE EFFICIENCY                       89.73 %

OUTLET PARTICLE DISTRIBUTION OF STAGE 1
                                               INLET        OUTLET
                                PARTICLE SIZE ACC. WGT.    ACC. WGT.
                                  LESS THAN    PERCENT      PERCENT
                                     1.27        1.0          9.73
                                     5.55        6.0         58.22
                                    12.40       11.0         85.32
                                    24.89       16.0         92.80
                                    46.62       21.0         95.84
                                    77.81       26.0         96.93
                                    81.67       31.0         97.44
                                    85.54       36.0         97.85
                                    89.41       41.0         98.19
                                    93.27       46.0         98.45
                                    97.09       51.0         98.70
                                   100.88       56.0         98.93
                                   104.59       61.0         99.12
                                   108.23       66.0         99.29
                                   111.77       71.0         99.4[illegible]
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PROGRAM: BOCY10
                                        DATE: 10/20/72

                         THE DUCON CO. INC.                              A-II-38
                       147 E. SECOND STREET
                        MINEOLA, N.Y. 11501

CUSTOMER: FOSTER WHEELER

CUSTOMER REFERENCE NUMBER: FWC 11-5[illegible]531

DUCON REFERENCE NUMBER: P72-437

                           TABLE  2

   DUCON CYCLONE OPERATING AND DESIGN DATA SHEET

CYCLONE SELECTION: NO. OF STAGES
TOTAL GAS FLOW                                         1
TOTAL GAS FLOW AT OPERATING CONDITION             178059 LBS/HR
OPERATING GAS DENSITY @ COND.                      12847 ACFM
OPERATING VISCOSITY @ COND.                       0.2310 LBS/CF
OPERATING GAS TEMPERATURE                         0.0430 CP
OPERATING GAS PRESSURE                              1600 DEG.F.
PARTICLE DENSITY                                  169.70 PSIA
OPERATING SOLIDS INLET LOADING                      42.0 LBS/CF
OPERATING SOLIDS INLET LOADING                      2940 LBS/HR
                                                   26.70 GRAINS/ACF
CYCLONE STAGES
CYCLONE SIZE                                       FIRST
CYCLONE TYPE                                         200
CYCLONE MODEL                                         VM
NO. OF CYCLONES                                      700
OPERATING GAS FLOW PER CYCLONE                         2
CYCLONE INLET VELOCITY                              6424 ACFM
CYCLONE SALTATION VELOCITY                          53.5 FT/SEC
CYCLONE FRACTIONAL EFFICIENCY CURVE NO.             22.0 FT/SEC
CYCLONE OUTLET TO INLET RATIO                       47.4
CYCLONE PRESSURE DROP                               1.50
CYCLONE DIP-LEG SUCTION                             15.0 IN.WG.
CYCLONE DIP-LEG DIAMETER                            21.7 IN.WG.
DIP-LEG SOLIDS RATE                                    8 IN.
CYCLONE SOLIDS LOSS RATE                            1.05 LBS/SEC-SQ.FT.
CYCLONE SOLIDS EMISSION                           307.11 LBS/HR
ACC. CYCLONE EFFICIENCY                            2.789 GR/ACF
                                                   89.55 %
OUTLET PARTICLE DISTRIBUTION OF STAGE 1
                                         INLET          OUTLET
                        PARTICLE SIZE  ACC. WGT.      ACC. WGT.
                          LESS THAN     PERCENT        PERCENT
                             1.27         1.0           9.57
                             5.55         6.0          57.29
                            12.40        11.0          84.91
                            24.89        16.0          92.49
                            46.62        21.0          95.56
                            77.81        26.0          96.69
                            81.67        31.0          97.23
                            85.54        36.0          97.68
                            89.41        41.0          98.05
                            93.27        46.0          98.34
                            97.09        51.0          98.59
                           100.88        56.0          98.83
                           104.59        61.0          99.03
                           108.23        66.0          99.22
                           111.77        71.0          99.30
```

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PROGRAM: BOCY10                               DATE: 10/20/72

                     THE DUCON CO. INC.
                   147 E. SECOND STREET
                    MINEOLA, N.Y. 11501

CUSTOMER: FOSTER WHEELER

CUSTOMER REFERENCE NUMBER: FWC 11-52331

DUCON REFERENCE NUMBER: P72-437

                        TABLE  3

   DUCON CYCLONE OPERATING AND DESIGN DATA SHEET

CYCLONE SELECTION: NO. OF STAGES                       1
TOTAL GAS FLOW                                    273735 LBS/HR
TOTAL GAS FLOW AT OPERATING CONDITION              19750 ACFM
OPERATING GAS DENSITY @ COND.                     0.2310 LBS/CF
OPERATING VISCOSITY @ COND.                       0.0430 CP
OPERATING GAS TEMPERATURE                           1600 DEG.F.
OPERATING GAS PRESSURE                            169.70 PSIA
PARTICLE DENSITY                                    42.0 LBS/CF
OPERATING SOLIDS INLET LOADING                      4892 LBS/HR
OPERATING SOLIDS INLET LOADING                     28.90 GRAINS/ACF

CYCLONE STAGES                                     FIRST
CYCLONE SIZE                                         200
CYCLONE TYPE                                          VM
CYCLONE MODEL                                        700
NO. OF CYCLONES                                        3
OPERATING GAS FLOW PER CYCLONE                      6583 ACFM
CYCLONE INLET VELOCITY                              54.9 FT/SEC
CYCLONE SALTATION VELOCITY                          22.0 FT/SEC
CYCLONE FRACTIONAL EFFICIENCY CURVE NO.             47.1
CYCLONE OUTLET TO INLET RATIO                       1.50
CYCLONE PRESSURE DROP                               15.7 IN.WG.
CYCLONE DIP-LEG SUCTION                             22.6 IN.WG.
CYCLONE DIP-LEG DIAMETER                               8 IN.
DIP-LEG SOLIDS RATE                                 1.16 LBS/SEC-SQ.FT.
CYCLONE SOLIDS LOSS RATE                          508.69 LBS/HR
CYCLONE SOLIDS EMISSION                            3.005 GR/ACF
ACC. CYCLONE EFFICIENCY                            89.60 %

OUTLET PARTICLE DISTRIBUTION OF STAGE 1
                                                INLET        OUTLET
                           PARTICLE SIZE      ACC. WGT.     ACC. WGT.
                             LESS THAN         PERCENT       PERCENT
                               1.27              1.0           9.62
                               5.55              6.0          57.55
                              12.40             11.0          85.03
                              24.89             16.0          92.58
                              46.62             21.0          95.64
                              77.81             26.0          96.76
                              81.67             31.0          97.29
                              85.54             36.0          97.73
                              89.41             41.0          98.09
                              93.27             46.0          98.37
                              97.09             51.0          98.62
                             100.88             56.0          98.85
                             104.59             61.0          99.06
                             108.23             66.0          99.24
                             111.77             71.0          99.40
```

147 E. SECOND STREET
MINEOLA, N.Y. 11501

CUSTOMER: FOSTER WHEELER

CUSTOMER REFERENCE NUMBER: FWC 11-52331

DUCON REFERENCE NUMBER: P72-437

TABLE 3A

DUCON CYCLONE OPERATING AND DESIGN DATA SHEET

CYCLONE SELECTION: NO. OF STAGES	1.
TOTAL GAS FLOW	205128 LBS/HR
TOTAL GAS FLOW AT OPERATING CONDITION	14800 ACFM
OPERATING GAS DENSITY @ COND.	0.2310 LBS/CF
OPERATING VISCOSITY @ COND.	0.0430 CP
OPERATING GAS TEMPERATURE	1600 DEG.F.
OPERATING GAS PRESSURE	169.70 PSIA
PARTICLE DENSITY	42.0 LBS/CF
OPERATING SOLIDS INLET LOADING	3666 LBS/HR
OPERATING SOLIDS INLET LOADING	28.90 GRAINS/ACF

CYCLONE STAGES	FIRST
CYCLONE SIZE	200
CYCLONE TYPE	VM
CYCLONE MODEL	700
NO. OF CYCLONES	3
OPERATING GAS FLOW PER CYCLONE	4933 ACFM
CYCLONE INLET VELOCITY	41.1 FT/SEC
CYCLONE SALTATION VELOCITY	18.0 FT/SEC
CYCLONE FRACTIONAL EFFICIENCY CURVE NO.	52.8
CYCLONE OUTLET TO INLET RATIO	1.50
CYCLONE PRESSURE DROP	8.8 IN.WG.
CYCLONE DIP-LEG SUCTION	13.8 IN.WG.
CYCLONE DIP-LEG DIAMETER	8 IN.
DIP-LEG SOLIDS RATE	0.86 LBS/SEC-SQ.FT.
CYCLONE SOLIDS LOSS RATE	415.36 LBS/HR
CYCLONE SOLIDS EMISSION	3.274 GR/ACF
ACC. CYCLONE EFFICIENCY	88.67 %

OUTLET PARTICLE DISTRIBUTION OF STAGE 1

RUN AT
75% OF
TABLE 3

PARTICLE SIZE LESS THAN	INLET ACC. WGT. PERCENT	OUTLET ACC. WGT. PERCENT
1.27	1.0	8.83
5.55	6.0	52.96
12.40	11.0	82.54
24.89	16.0	90.82
46.62	21.0	94.08
77.81	26.0	95.39
81.67	31.0	96.09
85.54	36.0	96.70
89.41	41.0	97.23
93.27	46.0	97.68
97.09	51.0	98.06
100.88	56.0	98.37
104.59	61.0	98.63
108.23	66.0	98.86
111.77	71.0	99.08
115.19	76.0	99.27
118.48	81.0	99.45
121.62	86.0	100.00

CUSTOMER: FOSTER WHEELER

CUSTOMER REFERENCE NUMBER: FWC 11-52331

DUCON REFERENCE NUMBER: P72-437

TABLE 3B

DUCON CYCLONE OPERATING AND DESIGN DATA SHEET

CYCLONE SELECTION: NO. OF STAGES	1
TOTAL GAS FLOW	136868 LBS/HR
TOTAL GAS FLOW AT OPERATING CONDITION	9875 ACFM
OPERATING GAS DENSITY @ COND.	0.2310 LBS/CF
OPERATING VISCOSITY @ COND.	0.0430 CP
OPERATING GAS TEMPERATURE	1600 DEG.F.
OPERATING GAS PRESSURE	169.70 PSIA
PARTICLE DENSITY	42.0 LBS/CF
OPERATING SOLIDS INLET LOADING	2446 LBS/HR
OPERATING SOLIDS INLET LOADING	28.90 GRAINS/ACF

CYCLONE STAGES	FIRST
CYCLONE SIZE	200
CYCLONE TYPE	VM
CYCLONE MODEL	700
NO. OF CYCLONES	3
OPERATING GAS FLOW PER CYCLONE	3292 ACFM
CYCLONE INLET VELOCITY	27.4 FT/SEC
CYCLONE SALTATION VELOCITY	13.0 FT/SEC
CYCLONE FRACTIONAL EFFICIENCY CURVE NO.	75.4
CYCLONE OUTLET TO INLET RATIO	1.50
CYCLONE PRESSURE DROP	3.9 IN.WG.
CYCLONE DIP-LEG SUCTION	7.3 IN.WG.
CYCLONE DIP-LEG DIAMETER	8 IN.
DIP-LEG SOLIDS RATE	0.55 LBS/SEC-SQ.FT.
CYCLONE SOLIDS LOSS RATE	360.08 LBS/HR
CYCLONE SOLIDS EMISSION	4.254 GR/ACF
ACC. CYCLONE EFFICIENCY	85.28 %

OUTLET PARTICLE DISTRIBUTION OF STAGE 1

RUN AT 50% OF TABLE 3

PARTICLE SIZE LESS THAN	INLET ACC. WGT. PERCENT	OUTLET ACC. WGT. PERCENT
1.27	1.0	6.79
5.55	6.0	40.76
12.40	11.0	71.65
24.89	16.0	83.78
46.62	21.0	87.78
77.81	26.0	89.60
81.67	31.0	90.80
85.54	36.0	91.90
89.41	41.0	92.90
93.27	46.0	93.82
97.09	51.0	94.66
100.88	56.0	95.43
104.59	61.0	96.14
108.23	66.0	96.79
111.77	71.0	97.38
115.19	76.0	97.93
118.48	81.0	98.43
121.62	86.0	98.89
124.60	91.0	99.31
127.39	96.0	100.00

DUCON

THE DUCON COMPANY, INC.
147 EAST SECOND STREET · MINEOLA, NEW YORK 11501
TEL: 516 741-6100 · CABLE: DUCON MINEOLANY · TWX 510 222-9861

November 10, 1972

Foster Wheeler Corp.
Process Design Department
Process Plants Division
110 South Orange Ave.
Livingston, New Jersey 07039

Attention: Mr. C.W. Chen

Subject: Ducon Proposal P72-437

Gentlemen:

In response to your request, I have roughly estimated the cost for eight (8) 8" Trickle Valves made out of Hastalloy 188 to be about twenty five thousand dollars ($25,000). This should not be taken as a final price. A finalized estimate would require my investigating the cost in much greater detail.

We hope the above is sufficient for your present needs and should you have any questions, please do not hesitate to contact us.

Very truly yours,
THE DUCON COMPANY, INC.
D. Buzzelli
D. Buzzelli

DB:aw

AERODYNE DEVELOPMENT CORPORATION

24340 MILES ROAD, CLEVELAND, OHIO 44128 • Telephone: 216/292-2828

November 7, 1972

Mr. C. W. Chen
Process Plants Division
Foster Wheeler Corporation
110 South Orange Ave.
Livingston, New Jersey 07039

Dear Mr. Chen:

Four (4) Model 4500 Type "S" Collectors fabricated of Hastellory 188 would cost $42,000 each for a total of $168,000, fabricated 10 gauge.

Our quotation is good for 90 days, prices are F.O.B. Cleveland, Ohio. Our terms are net 30 days.

Thanking you, we are

Very truly yours,

AERODYNE DEVELOPMENT CORP.

Mack Gordon

MG:rec

DUST COLLECTORS • LIQUID-SOLID SEPARATORS • MATERIAL HANDLING VALVES • OIL SKIMMERS

DUCON

THE DUCON COMPANY, INC.
147 EAST SECOND STREET · MINEOLA, NEW YORK 11501
TEL: 516 741-6100 · CABLE: DUCON MINEOLANY · TWX 510 222-9861

September 27, 1972

Foster Wheeler Corporation
110 South Orange Avenue
Livingston, New Jersey 07039

Attention: Mr. C. Chen
Process Design Department
Process Plants Division

Subject: Ducon Proposal P72-437
Granular Bed Filter

Gentlemen:

In accordance with your inquiry dated September 16, 1972, we are pleased to offer our proposal on a Ducon Granular Bed Filter for use as a secondary particulate removal pressurized system.

General Arrangement

For this service our selection consists of two (2) Size 51/204 GB filter units operating in parallel.

Note, that the two filters should be arranged for connection to a common gas inlet line. Each filter unit during normal operating would handle 1/2 of the total gas flow. The clean gas from each should discharge to a common gas line. This arrangement can be modified to suit the plant's requirements.

Within this arrangement one of the two filters could be isolated by means of valving on the gas inlet and gas outlet, without interrupting the operation of the other filter.

AIR POLLUTION CONTROL EQUIPMENT · PNEUMATIC CONVEYING SYSTEMS

Ducon Proposal P72-437

Details of Construction

The filter consists of a Carbon Steel pressure vessel casing, furnished with a suitable thickness of internal insulating castable refractory lining. The refractory lining will be supported by Stainless Steel tines, welded to the vessel shell. The vessel is fitted with an internal Type 310 Stainless Steel plenum which supports the filter elements and acts as a clean gas collection chamber.

*Each vessel will be shipped in two major pieces, an upper section containing the shop installed plenum and a lower cone section, thus a circumferential field weld on the shell would be required. The filter elements, filter blow back manifolds, internal inlet ducts, walkways, etc., would be shipped loose for field installation. The erection sequence would be as follows:

1. Erect vessel support structure.
2. Move lower cone section with loose internals to inside support structure.
3. Install vessel upper section on support structure.
4. Install erection clips at field seam.
5. Move bottom cone section into place and secure with erection clips.
6. Weld circumferential seam.
7. Install target plate and platforms.
8. Gun castable refractory on vessel shell.
9. Install filter elements.
10. Install external blow back piping.
11. Make external piping connections.

*NOTE: The number of pieces and sections of each module, and the amount of field welding required may vary depending on shipping limitations from point of manufacture to plant site.

Ducon Proposal P72-437

Performance

Based on your process conditions and the dust characteristics which you indicate, we would anticipate that the Ducon Type GB Filter would operate at an efficiency of approximately 98%. Not having experience with this process, we would strongly recommend that a pilot operation be initiated prior to a commercial unit.

Prices

We would estimate that the approximate selling price for these units would be as follows:

•Vessels	$162,000 Each
•Filter elements (310 Stainless Steel)	$ 41,400/Module
•Blow back piping, valving and instruments	$ 8,470/Module

With regard to the design of the vessels required to encase the Ducon Granular Bed Filter and the structural steel support required for these modules, preliminary calculations indicate that at 175 PSIG design pressure and 650° shell design temperature, material thicknesses in excess of 1¼ inches would be required. Furthermore, due to the extremely high internal temperature and pressure, the blow back system would have to be specially designed also. The analysis required in order to properly design these vessels is involved and time consuming.

The Ducon Company has the capability of performing this design work for a fee of seven thousand dollars ($7,000.00), which includes five thousand five hundred dollars ($5,500.00) for the vessel and structural design and one thousand five hundred dollars ($1,500.00) for the special design of the backwashing system.

This amount will be credited toward a Purchase Order for the Ducon Granular Bed Filter for this service, if the project were to proceed.

•NOTE: Two vessels are required.

Ducon Proposal P72-437

Delivery of equipment could be made approximately four to six months after receipt of approval drawings, and we would estimate that the field erection time would be one to one and a half months. We are enclosing three copies of our Process Data Sheet and three copies of our sketch SP72-437-1 for your inspection.

We hope that the above and enclosed is satisfactory for your present needs, and if we may be of further service please do not hesitate to contact us.

Very truly yours,
THE DUCON COMPANY, INC.

A. Tesoriero

AT:aw
cc: B. Kalen

Operating Data Sheet for Granular Bed Filter

Customer: Foster Wheeler Corporation

Customer Reference: FWC11-52331

Ducon Reference: P72-437

	CASES	A.1	A.2	A.3
Number of Units		2	2	2
Size of Unit			2-51/204	
Total Gas Flow	SCFM	60,500	39,500	89,000
Total Gas Flow at Condition	ACFM	19,665	12,791	27,038
Gas Molecular Weight		30.16	30.04	30.3
Gas Temperature	°F	1600	1600	1600
Gas Pressure	PSIA	155	155	155
Gas Density at Condition	#/CFT	0.232	0.231	0.233
Gas Viscosity at Condition	Cp	.043	.043	.043
Apparent Particle Density	#/CFT	42	42	42
Inlet Dust Load	#/HR	398.12	237.05	500.37
Inlet Dust Load	GR/ACFT	2.362	2.162	2.159
Filter Efficiency	%		98+	
Outlet Dust Load	#/HR	8	4.8	10
Outlet Dust Load	GR/ACFT	.0475	.0438	.0432
Outlet Dust Load	GR/SCFT	.0155	.0142	.0132
Total Bed Area	FT^2	408	408	408
Flow to Bed Ratio		48.2	31.4	66.3
Superficial Bed Velocity	FPS	.805	.523	1.11
Pressure Drop	IN W.G.	20-23	10-15	28-33
Design Backwash Cycle	Min.	5	5	5
Backwash Flow Required	SCFM	450	450	450
Backwash Pressure Required	PSIG		360	
No. of Filter Elements			51/Module	
No. of Compt. per Element			16	
Grade of Sand			1/4	

Operating Data Sheet for Granular Bed Filter

Customer: Foster Wheeler Corporation

Customer Reference: FWC11-52331

Ducon Reference: P72-437

Reproduced from best available copy.

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Operating Data Sheet for Granular Bed Filter

Customer: Foster Wheeler Corporation

Customer Reference: FWC11-52331

Ducon Reference: P72-437

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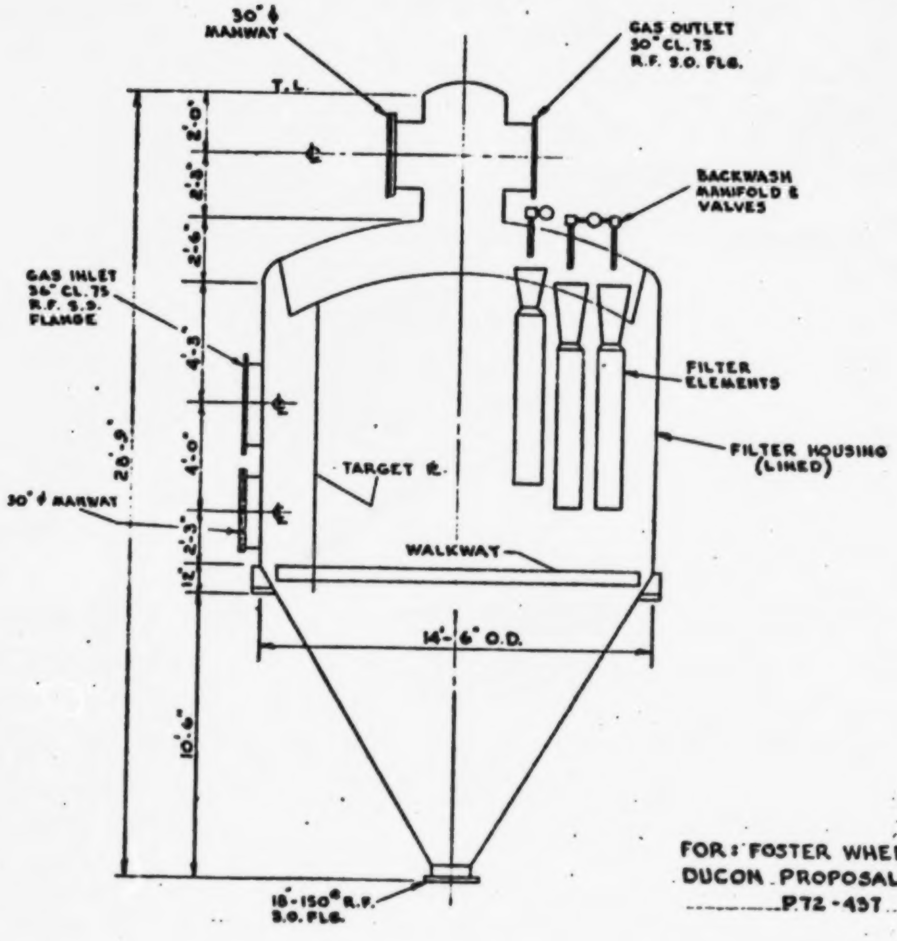
Backwash Pressure Required	PSIG		360	
No. of Filter Elements			51/Module	
No. of Compt. per Element			16	
Grade of Sand			1/4	

A-II-51/52/53

CONSTRUCTION SPECS
HOUSING: A-515 GR-55
LINING: 4" "ONE-SHOT" WITH TINE CLIPS
SHELL TEMP FOR DESIGN 650° F.
DESIGN PRESSURE 175 PSIG
JOINT EFF. (SPOT X-RAY) 0.85

FILTER ELEMENTS	SS 310	
WALKWAY	SS 310	
INTERNAL PLENUM	SS 310	1/4" THK. MIN.
TARGET PLATE	SS 310	1/4" THK. MIN.



FOR: FOSTER WHEELER.
DUCON PROPOSAL:
P.72-437

2-UNITS REQUIRED
SIZE 51/204

SKETCH NO. SP72-437-1

FMC CORPORATION

LINK-BELT MATERIAL HANDLING SYSTEMS DIVISION

3400 WALNUT STREET, COLMAR, PENNSYLVANIA 18915 • TELEPHONE: (215) 822-0861

September 14, 1972

Foster Wheeler Corporation
110 South Orange Avenue
Livingston, N. J. 07039

Attention: Mr. C. W. Chen

Subject: Spent Dolomite Cooler
Westinghouse Research Laboratory
Your Inquiry No. FW 11-52331
Item RC-101

Dear Mr. Chen:

Thank you for your inquiry of August 23 which was received here on August 30. We trust the delay in getting an answer to you has not inconvenienced you too greatly.

Based upon the information supplied to us, we are pleased to offer a tentative recommendation of a roto fin cooler to handle spent dolomite and fly ash from 1600° to 1750° initial temperature, and cool down to about 300° F. For design purposes we are assuming a feed temperature of 2000° F. however and cooling down to 300° F. at the rate of 24.5 TPH.

Our tentative selection would be our No. 600 RF16 Roto-Fin Cooler. This unit would be as described in our Book 3406, a copy of which is attached for your reference. Page 25 of this book has some preliminary dimensional information which would be of help in determining space requirements.

We would include with the equipment a mild steel rotor of our tube design and which would be modified to handle the temperatures above. It would be complete with a drive and reducer, a hood, and tank, and temperature recorders for the inlet and outlet material temperatures.

FMC CORPORATION

LINK-BELT MATERIAL HANDLING SYSTEMS DIVISION

Page 2

September 14, 1972
Foster Wheeler Corporation

The approximate price for the above equipment would be $60,000.00 f.o.b. Colmar, Pa.

Delivery at the present time for this equipment is running about 25 weeks.

With the preponderance of small particles in the material, the biggest advantage here would be the lack of a requirement for any air moving through the unit. All of the cooling would be done indirectly with the use of water at 85°. However, to maintain a 120° exit water temperature, our calculations indicate that the pumping requirements would be something in the range of 1500 GPM. You may want to review the exit water requirement in view of the large amount of water needed.

After you have had a chance to look over our quotation, we would be pleased to discuss it with you at greater length. However, if you have any questions that need immediate answers, please don't hesitate to call us.

Very truly yours,

FMC CORPORATION

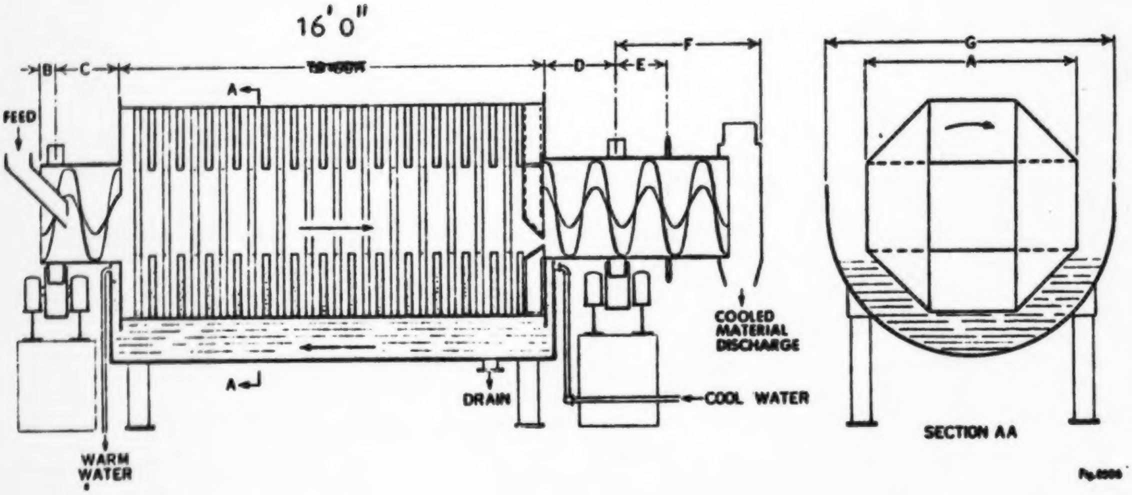
Link-Belt Material Handling Systems Division

V. A. Cheney
Manager
Dryers and Coolers

Sr.

VAC/sb
Encl.

RC-101 Dolomite Cooler



Roto-Fin number	A	B	C	D	E	F	G
	FEET AND INCHES						
300	3-0	0-4	0-9	0-9	1-0	2-3	4-6
400	4-0	0-4	1-0	1-0	1-2	2-9	5-4
600	6-0	0-6	1-10	1-10	1-4	3-9	7-8
800	8-0	0-8	2-4	2-4	2-0	5-0	10-8
1000	10-0	0-10	3-4	3-4	2-8	6-3	13-2

Have dimensions certified for installation purposes.

Peabody Engineering Corp
835 Hope Street | Stamford, Connecticut 06907 | Telephone 203 327-7000

Peabody Engineering

Peabody Proposal No. 72-306

November 27, 1972

Foster Wheeler Corporation
110 South Orange Avenue
Livingston, New Jersey 07039

Attention: Mr. Chen

Reference: Pressurized Air Heater
PEC Proposal No. 72-306

Gentlemen:

This letter is to confirm the information related verbally to your Mr. Chen at our meeting on November 16.

In review, the system is to be designed for the following conditions:

Heat release	35.0 MM BTU/hr.
Inlet temperature	500° F.
Outlet temperature	1500° F.
Furnace pressure (operating)	150 PSIG
Furnace pressure (design)	320 PSIG
Fuel	No. 2 oil
Atomization	Steam
Atomization pressure	100 PSIG above furnace pressure
Location	Outdoors
Arrangement	Vertical

The overall dimensions and weight of the equipment is as illustrated on the attached sketch. For vertical up-fired arrangement as illustrated on the attached sketch, add approximately 6'-6" to the length of the unit to obtain the elevation of the outlet flange above the supporting steel base plate.

We can furnish this unit complete with shell, super-duty firebrick and insulating material (shipped loose), burner, ignitor, FIA approved flame failure panel, oil valving and temperature controls, including electrically operated control valve, temperature controller and high temperature instrument. Our budget price for this equipment is THIRTY-ONE THOUSAND ONE HUNDRED FORTY DOLLARS ($31,140.00).

continued...

The equipment would be supplied with all components, except flame failure panel, shipped loose for wiring and piping by your personnel in the field. If you choose to have Peabody complete all such piping and wiring in our shops prior to shipment we would charge an additional TWO THOUSAND SIX HUNDRED DOLLARS ($2,600.00) for that service.

Further if you choose to deduct the temperature controls from our supply our price will be reduced by TWO THOUSAND FIVE HUNDRED DOLLARS ($2,500.00).

Our preliminary price for a Duplex pump set to supply the oil at 300 PSIG is THREE THOUSAND FIVE HUNDRED DOLLARS ($3,500.00).

All prices are net, F.O.B. shipping points.

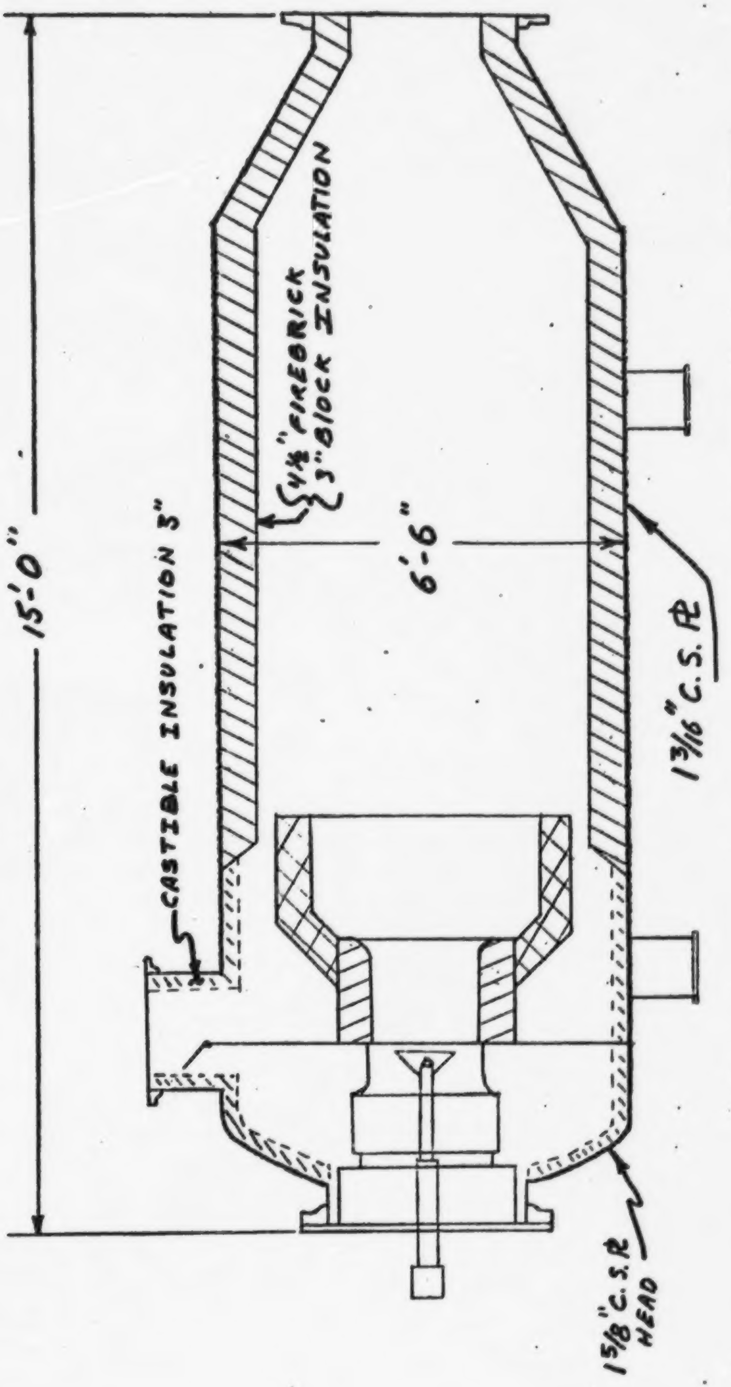
If further requirements evolve on this project on either this portion or the two (2) burners previously quoted, please contact the writer directly.

Yours very truly,
PEABODY ENGINEERING

Felix D'Avanzo

FD'A/mp
Letter in Duplicate

Reproduced from best available copy.



OPERATING: 150 PSIG
DESIGN: 320 PSIG
INLET TEMP: 500°F

FOSTER WHEELER CORP.

REF. PROP 72-306
NOV. 27, 1972

DIRECT FIRED AIR HEATER

DWG NO. E-72-306